Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

Mineral Sciences Laboratories
Laboratoires des sciences minérales

Canada

MINERAL SCIENCES LABORATORIES

ANNUAL REPORT 1988/89

CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY

ENERGY, MINES AND RESOURCES CANADA

DIVISION REPORT MSL 89-58 (TR)

This document is an unedited interim report prepared primarily for discussion and internal reporting purposes. It does not represent a final expression of the opinion of the Canada Centre for Mineral and Energy Technology (CANMET)

Ce document est un rapport provisoire non-revisé et rédigé principalement pour fin de discussion et de documentation interne. Il ne représente nullement l'expression définitive de l'opinion du Centre canadien de la technologie des minéraux et de l'énergie (CANMET)

142 pp

MICROMEDIA

FOREWORD

The Mineral Sciences Laboratories is issuing two annual reports for 1988/89. This present report is considered to be internal and contains detailed descriptions of projects and outputs; it is a historical record. The second report to be extracted from this one will be much shorter, will only give an overview of the past year's activities and will be directed at our external clientele. This new initiative should permit a much broader and effective distribution and general communication with industry.

This annual report reflects some of the commitments which were reported in the CANMET Business Plans. Specific items are highlighted to indicate new directions and also to reflect on accomplishments.

The preparation of an annual report enlists goodwill and effort of the entire staff; special acknowledgement should go to Susan Lord and Lloyd Dalton, who co-ordinated the report, and to Joan Villeneuve for technical and editorial endeavors. Mr. Gilles Tremblay and Serge Duguay will be co-ordinating the other document.

Comments from readers are welcome and should be directed to:

L.L. Sirois
Director
Mineral Sciences Laboratories

AVANT-PROPOS

Les Laboratoires des sciences minérales publieront deux rapports annuels pendant l'année financière 1988/89. Le présent document est diffusé à l'échelle internationale et comprend des descriptions précises des projets et réalisations des LSM; il s'agit d'un exposé historique. Le deuxième rapport sera tiré du premier et sera beaucoup plus bref, ne donnant qu'un aperçu des activités de l'an dernier. Il est destiné à nos clients de l'extérieur. Cette initive devrait nous permettre de donner de l'envergure à nos services de distribution et d'en optimiser l'efficacité tout en facilitant nos rapports avec l'industrie.

Le rapport annuel reprend certains des engagements dont il est fait mention dans le Rapport d'entreprise de CANMET. Des sujets spécifiques y sont abordés en vue de souligner les nouvelles orientations des LSM et, également, de rendre compte des réalisations et succès obtenus.

La préparation du rapport annuel exige les efforts et la participation de tout le personnel. Les coordonnateurs de la publication, Susan Lord et Lloyd Dalton, de même que Joan Villeneuve, qui n'ont épargné ni temps ni efforts, méritent d'être félicités pour leur travail. Les coordonnateurs de la seconde publication sont Gilles Tremblay et Serge Duguay.

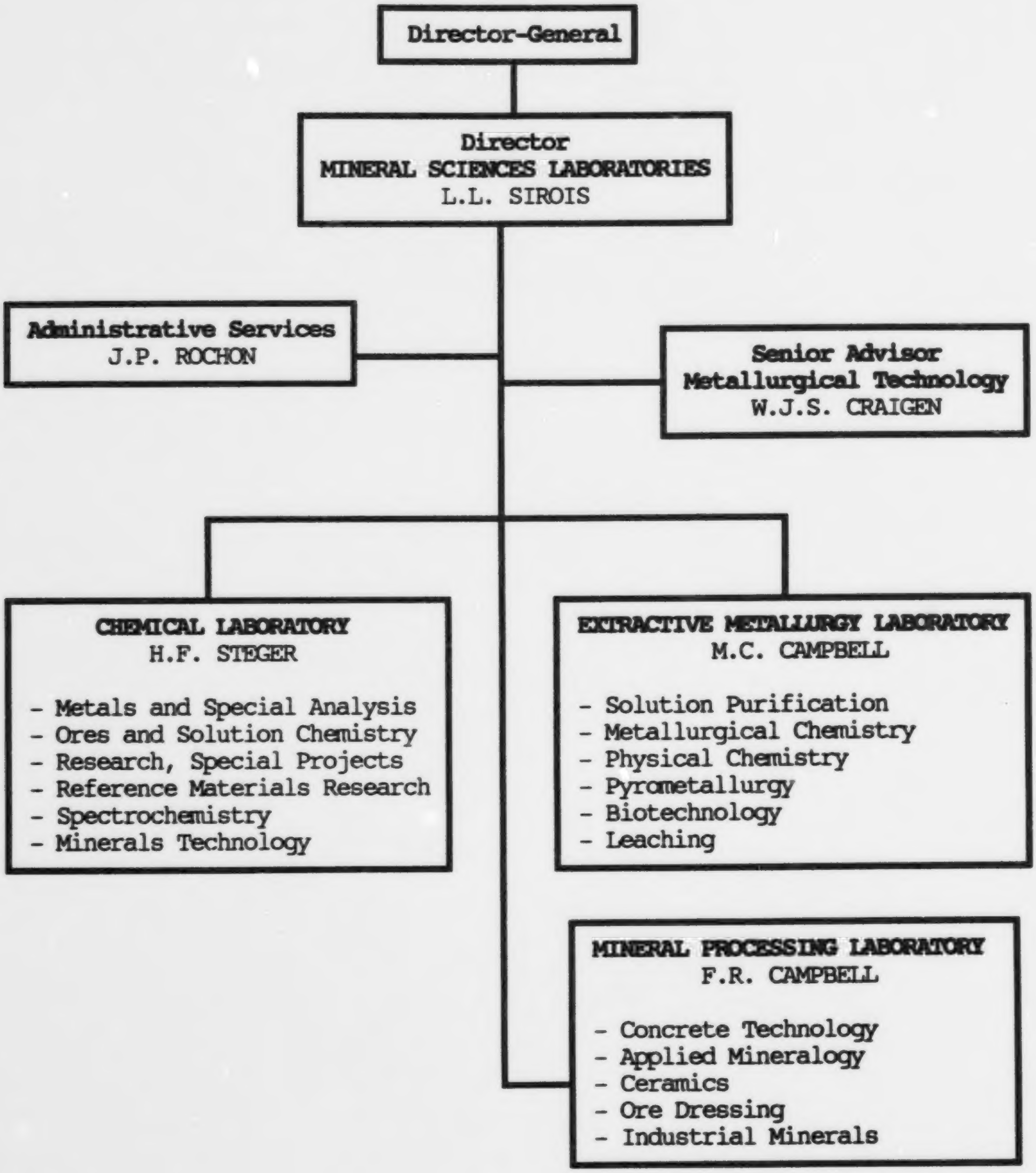
Vos commentaires sont fort appréciés. Veuillez s.v.p. les adresser à:

L.L. Sirois
Directeur
Laboratoires des sciences minérales

ORGANIZATION AND PROFESSIONAL STAFF

CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY (CANMET)

MINERAL SCIENCES LABORATORIES


Director-General
Director
MINERAL SCIENCES LABORATORIES
L.L. SIROIS
Administrative Services
J.P. ROCHON
Senior Advisor
Metallurgical Technology
W.J.S. CRAIGEN
CHEMICAL LABORATORY
H.F. STEGER
- Metals and Special Analysis
- Ores and Solution Chemistry
- Research, Special Projects
- Reference Materials Research
- Spectrochemistry
- Minerals Technology
EXTRACTIVE METALLURGY LABORATORY
M.C. CAMPBELL
- Solution Purification
- Metallurgical Chemistry
- Physical Chemistry
- Pyrometallurgy
- Biotechnology
- Leaching
MINERAL PROCESSING LABORATORY
F.R. CAMPBELL
- Concrete Technology
- Applied Mineralogy
- Ceramics
- Ore Dressing
- Industrial Minerals

DISTRIBUTION OF RESOURCES

MSL - FISCAL YEAR 1988-89

PROGRAM - MINERAL AND EARTH SCIENCES
ACTIVITY - "A-BASE

SUB-ACTIVITY	MSL $000's
20. COAL MINING AND PREPARATION	
- Personnel (PY)	162(3)
- Operating	75
- Capital	18
30. MINERAL PROCESSING	
- Personnel (PY)	9355(173)
- Operating	1377
- Capital	278
50. FUELS TECHNOLOGY	
- Personnel (PY)	47(1)
- Operating	20
- Capital	20
70. METALS AND MATERIALS	
- Personnel (PY)	97(2)
- Operating	5
- Capital	6
ACTIVITY TOTAL	
- Personnel (PY)	9661(179)
- Operating	1477
- Capital	322

PROGRAM - MINERAL AND EARTH SCIENCES
ACTIVITY - ENERGY R&D

SUB-ACTIVITY	MSL $000's
20. COAL MINING AND PREPARATION	
- Personnel (PY)	Nil
- Operating	Nil
- Capital	230
30. MINERAL PROCESSING	
- Personnel (PY)	250(5)
- Operating	385
- Capital	125
50. FUELS TECHNOLOGY	
- Personnel (PY)	50(1)
- Operating	20
- Capital	30
70. METALS AND MATERIALS	
- Personnel (PY)	Nil
- Operating	Nil
- Capital	Nil
ACTIVITY TOTAL	
- Personnel (PY)	300(6)
- Operating	405
- Capital	385

PROGRAM - MINERAL DEVELOPMENT AGREEMENT
ACTIVITY - "A-BASE"

SUB-ACTIVITY	MSL $000's
30. MINERAL PROCESSING	
- Personnel (PY)	141(4)
- Operating	43.5
- Capital	Nil

PROGRAM - BIOTECHNOLOGY

ACTIVITY - "A-BASE"

SUB-ACTIVITY	MSL $000's
30. MINERAL PROCESSING	
- Personnel (PY)	Nil
- Operating	25
- Capital	Nil

HIGHLIGHTS

CHEMICAL LABORATORY

The Chemical Laboratory provides analytical support and carries out analytical method research for CANMET projects, other federal organizations and universities; provides the sole Canadian umpire analysis service for uranium concentrates; certifies reference materials; and participates in committee work for standardization bodies. The Laboratory performs research in and provides support to CANMET projects and outside organizations in Mossbauer spectrometry, magnetic susceptibility and infrared spectrometry.

The Laboratory maintains the chemical storesroom for MSL and other Divisions, provides a desktop publishing facility, acts as supervisor of the MSL management information system and provides support to MSL in health and safety issues such as WHMIS.

During 1988, the Operations Unit carried out 29,001 determinations of a wide variety of elements in approximately 8,637 samples. This year saw continuing cooperation and integration of effort between Sections. Because of retirements, the Operations Unit was re-organized into three Sections from five.

The Laboratory's capability to determine microgram levels of cobalt, nickel, lead, bismuth, indium and tellurium improved through the development of new atomic absorption methods in this review period. The rapid analysis of gold mill effluents for total cyanide, dissociable cyanide and thiocyanate was realized through the application of flow-injection techniques. Detection limits for rare earths in geochemical samples and alloys by high-performance liquid chromatography were lowered to 5 ng/ml.

Participation in national and international committee work continued with strongest effort for the International Organization for Standardization (ISO). Examples are REMCO, the Council Committee on Reference Materials; TC 102 for iron ore standards; and TC 183 for standard methods of chemical analysis of copper, lead and zinc ores and concentrates. Laboratory personnel made a significant contribution to the international meeting of ISO/TC 183 held in Ottawa in May.

At the request of an ASTM Task Force on Silica Fume, a CANMET gravimetric method for the determination of silica was evaluated and proposed for application to silica fume. A fusion-atomic absorption method proposed for consideration as an ISO standard method for the determination of calcium and magnesium in aluminum ores was evaluated at the request of Alcan International Limited.

The Canadian Certified Reference Materials Project (CCRMP) provided analytical laboratories with reference materials for use in quality control and method development. Revenue from the sale of CCRMP materials increased 14% to $166,000, with 64% of sales outside Canada. In 1988, a thorium/rare earth ore, a compressive strength monitor cement and a suite of four base metal tailings samples for the MEND Program were certified as reference materials. A major effort was initiated in cooperation with the Geological Survey of Canada for the preparation of platiniferous samples to serve as reference materials in geo-exploration analysis.

Work in mineral physics contributed significantly to research projects in other MSL laboratories and the Metals Technology Laboratories. Projects on copper anode slimes, ceramics and rapidly solidified materials are examples. A Fourier transform infrared spectrometer commercial was commissioned. It provides a capability for identifying the molecular structure of a material and for studying changes in this structure arising from treatment processes.

The Chemical Laboratory provided analytical support to many cost recovery projects in the Extractive Metallurgy and Mineral Processing Laboratories. Mineral physics research and measurement support assisted in cost recovery projects for Alcan International and Niobec. Non-routine analytical support and the preparation of reference materials was performed as cost recovery for outside agencies such as Environment Canada and Stillwater Mining.

EXTRACTIVE METALLURGY LABORATORY

The Extractive Metallurgy Laboratory serves the Canadian mineral industry through a comprehensive program of research and development. This scientific group performs work in the fields of applied chemistry, process metallurgy, biotechnology and environmental controls. The laboratory is comprised of a group of experienced professionals and technologists dedicated to strengthening the science and technology for the husbanding of the Canadian mineral resource base in close cooperation with the corporate sector of the industry. The wide range of research serves clientele in industry, government and universities.

The comprehensive research activities of the Extractive Metallurgy Laboratory are planned to strengthen the knowledge base in solution chemistry, inorganic compound formation, thermochemistry, electrochemistry and surface chemistry. Process developments are investigated to enhance industrial productivity, to improve process control, to increase product and by-product recovery, to enable exploitation of complex ores and to ameliorate environmental impact. Close liaison with industry is an increasingly important aspect of the planning, execution and delivery of research.

The effectiveness of the work of the laboratory is best measured in terms of the applicability of results in industry. Several significant developments are noted as follows:

(a) Biological decomposition of organic compounds causing operational and environmental problems;

(b) Exploitation of photochemical catalytic processes on surfaces of semiconducting materials to oxidize and destroy environmental contaminants;

(c) Application of statistical methods to harmonize measurement and results within the International Standards Organization.

(d) Elaboration of the thermochemical properties of arsenides in stack gases;

(e) Development of Eh-pH diagrams for the gold-thiourea system;

(f) Characterization of copper anodes, anode slimes and anode passivation in electrolytic copper refining;

(g) Alternatives for iron control in zinc processing have focussed on conversion of jarosite to hematite and on the use of solvent extraction to produce a commercial quality iron product;

(h) Assembly of the chemistry, resins, process evaluation and engineering of ion exchange system for gold into a Canadian consortium;

(i) Formation and morphology of elemental sulphur during ferric chloride leaching of chalcopyrite;

(j) Mine Environmental Neutral Drainage (MEND) organization established as a successor to RATS (Reactive Acid Tailings Stabilization).

In response to leadership at senior levels, the work of EML has become focussed on client needs within the mineral industry. Those projects with a potential to generate revenue for EML have been designated as critical. Projects with a high level of interaction with industrial clients have been given priority and special attention. A number of cooperative projects utilizing EML's expertise in leaching, solution purification, biotechnology and electrochemistry have been undertaken. Several patents have been successfully marketed to industry. Technology transfer to several commercial enterprises has been facilitated by EML in cooperation with IRAP, an NRC funding program.

Interactions with provincial agencies in cooperation with industry has resulted in advances in the treatment of complex sulphide ores, biological leaching and environmental improvement. The MEND program has advanced as the successor to RATS. A full time coordinator has been appointed. A board of directors and a management committee have been established. An outline of the research program leading to walk-away technology for sulphide tailings and waste rock has been published as a CANMET report.

Liaison with the international scientific community has been strengthened through linkages to the US Bureau of Mines in biotechnology, to the EEC in hydrometallurgy, to a consortium of zinc producers via Noranda, and through participation in international conferences in solvent extraction, zinc and copper. EML personnel also serve on several International Standards

Organization committees to insure that Canadian interests in mineral trade are respected.

Service to Canadian and international professional societies has been provided through organizing conferences, seminars and meetings, presentation of papers and chairmanship of sessions. Personnel serve on editorial boards of journals, as adjunct professors at universities, and as thesis supervisors. Advice to other federal departments and agencies plays a critical role in federal funding of industrial and university research.

Throughout this MSL annual report, further detail on projects is provided. Readers are encouraged to inquire into any areas of specific interest.

MINERAL PROCESSING LABORATORY

The Mineral Processing Laboratory carried out in-house investigations, joint projects and contract studies in support of the needs of the Canadian minerals industry. The program is developed in close consultation with industry and with the provinces (especially through Mineral Development Agreements) and is carried out in cooperation with industrial R&D performers, private research companies, provincial research organizations and universities. Major projects are underway in the processing of metallic ores and industrial minerals, in the development and testing of improved concretes, and in the preparation and characterization of ceramic materials and products. These activities are supported by a range of mineralogical investigations, particularly aimed at process design and optimization.

For a number of years, CANMET has been working with Surface Science Western on the application of new techniques (such as Secondary Ion Mass Spectrometry) to the study of the disposition of precious metals in ores. With the support of nine gold mining companies, a detailed investigation of the nature of "invisible" gold has shown that the method can quantitatively determine concentrations of gold within individual mineral grains, can identify the host minerals and can determine whether the gold is in solid solution in the host mineral. This information is being used to develop optimal processing strategies to increase the recovery of this "invisible" gold. In follow on work, CANMET and Noranda have begun a cooperative project on increasing recovery of their refractory gold ores.

CANMET, in cooperation with the GSC, has developed new grade control instrumentation. Trials on drill core have shown its effectiveness in determining asbestos grade and a variation has been successfully tested on determination of manganese in iron ore. Further field testing is planned with support by industry.

New releases of programs in the SPOC family have proven popular. Following the announcement of the new release in March 1988, requests for the material balance program MATBAL have undergone a new surge in Canada and abroad. A new version of BILMAT, a more powerful material balance program, has since been released as have revised versions of RTD (for Residence Time Distribution) and CRSHEX (for crushing plant design). A demo disk is available on request and a new sales, distribution and control system for managing SPOC software is being commissioned.

A joint project with Kidd Creek Mines to develop an expert system for on-line data validation and substitution was successfully completed. The system checks and, if necessary, substitutes examined values for missing data from the XRF analyser in the Kidd Creek Cu/Zn flotation plant.

A major project conducted by Wabush Mines under the Canada/Newfoundland Mineral Development Agreement has reached the stage where the economic impact of the improved flowsheet can be assessed. The resulting increased recovery is expected to result in reduced operating costs of at least $500,000/y.

An automated, fully instrumented flotation column has been installed and commissioned as part of MSL's Continuous Process Development Unit. A number of ores have been treated for specific clients and a large joint CANMET/industry project is being developed.

The first three of a series of "Summary Reports" on individual industrial minerals have been issued (barite, celestite and fluorite). Each report collects together all of the results of beneficiation testing done at CANMET (or the Mines Branch) over the past 50 years or so, reviews the known deposits and their status and outlines current activities for the subject mineral. The series will, over the next year, be expanded to include virtually all Canadian industrial minerals with which CANMET worked.

In concrete technology, MSL began several years ago to examine the occurrences and causes of, mitigation strategies for alkali aggregate reactivity (AAR). AAR is responsible for extensive deterioration of massive concrete structures. The problem is much more widespread than first thought; CANMET sponsored studies in New Brunswick, Nova Scotia and Quebec have identified numerous examples. CANMET work has identified a number of potentially reactive rock types, is developing and evaluating accelerated test methods for screening aggregate sources and evaluating the role of supplementary cementing materials in controlling AAR.

Interest in CANMET's high volume fly ash concrete continues to grow. A major joint project is underway with Hydro Quebec and Ciment St. Laurent to develop additional engineering data to evaluate its use in hydro dam construction. A study by Trow Ltd. (Brampton, Ontario) is developing additional data for applications involving less massive structures (e.g., building construction).

In ceramics, CANMET has received a US Patent for its copyright solid electrolyte "Hyceram". Applications in hydrogen (and hydrogen isotope) sensing and pumping are being developed jointly with AECL. The material is being evaluated in a number of countries (Germany, Israel, US, Belgium, Denmark, Japan, UK) for fuel cell applications.

MSL is continuing to work with a number of advanced ceramic manufacturers to develop improved materials. Piezoelectric and electrostrictive materials based on a range of polycrystalline doped titanates and niobates is the subject of joint work with a Canadian manufacturer. A member of this company has been seconded full time into our labs. In structural ceramics, MSL is working with an industrial partner on the use of zirconia-toughened alumina and mullite for wear resistant applications. The ceramics group is also collaborating on silicon carbide technology for use in ceramic-ceramic composites.

MINERAL DEVELOPMENT AGREEMENTS

Commencing in 1984/85, under the "umbrella" of Economic and Regional Development Agreements the federal government negotiated Mineral Development Sub-Agreements (MDA's) with all provinces except Alberta and with both Territories. The objective of these agreements is to strengthen and diversify the mineral industry within a province, thus enabling minerals to make a maximum contribution to the provincial economy.

Most of these MDA's officially ended March 31, 1989 and are operating within the framework of a final "wrap-up" year. Exceptions to the above are Ontario, Northwest Territories and Quebec whose official completion dates are March 31, 1990, March 31, 1991 and March 31, 1990 respectively.

CANMET's Mineral Sciences Laboratories (MSL) is responsible for all processing technology for those MDA's in which a Research and Technology component was agreed upon. Thus, MSL is involved directly in MDA's with Newfoundland, Nova Scotia, New Brunswick, Manitoba and Saskatchewan and plays an advisory role in Agreements with Quebec, British Columbia, Yukon, Northwest Territories and Prince Edward Island.

MSL's role is, in consultation with the provinces, to prepare work programs, provide expert advice and guidance and act as Scientific Authorities on contracts. More than 69 separate contracts involving processing technology have been initiated to date. Total expenditures for 1988/89 are forecast at slightly more than $1.8 M.

During FY 1988/89 the main effort under the Newfoundland MDA was directed toward improved iron ore processing, improved iron ore binders and the evaluation of aggregates. For Nova Scotia work continued on development of engineering data for the use of fly ash in concrete, the evaluation of alkali reactivity of aggregates and evaluation of the production of barium chemicals.

Under the New Brunswick MDA work involved a marketability assessment of the Ferric Chloride Leach (FCL) Process for complex sulphide ores and evaluation of aggregates for alkali reactivity. For Manitoba work emphasis continued on SO_2 abatement, recovery of precious metals from zinc pressure leach residues and evaluation of the Bird River chromite deposits. Saskatchewan MDA work involved potash tailings disposal.

In subsequent sections of this document, MDA contracts are described as part of the project under which they fall (e.g., the Newfoundland MDA contracts on iron ore are described under the MSL Project Iron Ore Processing). MDA contracts are designated as such by the letters MDA, written after the Contract Requisition Number.

SPECIAL AWARDS

Dr. J.E. Dutrizac was elected a fellow of the Canadian Institute of Mining and Metallurgy in recognition of his services to the profession and for his research in extractive metallurgy.

Dr. W. Petruk received the Distinguished Lecturers Award from the Canadian Institute of Mining and Metallurgy.

The Applied Mineralogy Section received a $5,000 Public Service Merit Award for exceptional productivity and demonstrated excellence for more than a decade.

The Biotechnology Section received a $4,200 Public Service Merit Award for its exceptionally high level of achievement in the emerging field of applied biotechnology.

Randell Walker, a Co-op student from Waterloo University, working in the Solution Purification Section of EML from May-August, 1988, received the Sandford Fleming Foundation Work Report Award.

CONTENTS

PART A. RESEARCH AND DEVELOPMENT

MINERAL AND ENERGY TECHNOLOGY ACTIVITY

Page

COAL MINING AND PREPARATION SUB-ACTIVITY

Coal Desulphurization 1
Project 20.79.01 High Sulphur Coal 1

MINERAL PROCESSING SUB-ACTIVITY

Minerals Evaluation 3
Project 30.05.02 Mineralogical Evaluation of Process Products 3
Project 30.05.03 Mineralogical Characterization of Ores 5

Beneficiation - Metallic 6
Project 30.13.01 Computer Aided Mineral Processing (CAMP) 6
Project 30.13.02 Iron Ore Processing 8
Project 30.13.07 Beneficiation of Complex and Refractory Ores 10

Beneficiation - Industrial Minerals 12
Project 30.21.01 Energy Conservation in Industrial Mineral Processing 12
Project 30.21.02 Beneficiation/Grinding Studies of Industrial Minerals 14

Treatment - Ceramics 17
Project 30.29.01 Preparation and Characterization of Advanced Ceramic Materials 17
Project 30.29.05 Refractories for Steelmaking 20

Treatment - Industrial Minerals 22
Project 30.37.01 Performance and Durability of Concrete Incorporating Supplementary Cementing Materials 22
Project 30.37.02 Concrete for Offshore Structure 26
Project 30.37.03 Aggregate/Concrete Testing and Standards 28

Biotechnology 29
Project 30.46.01 Bioprocessing 29
Project 30.46.03 Photoelectrochemistry of Semiconducting Minerals 36
Project 30.46.04 Plasma 37

CONTENTS (Cont'd)

Page

Extraction - Metallics 39
Project 30.52.05 Impurities in Copper Refining 39
Project 30.52.07 Nonferrous Smelter Technology 41
Project 30.52.08 Zinc Processing 47
Project 30.52.09 Chloride Metallurgy 50

Extraction - Rare Metals 54
Project 30.61.02 Gold 54
Project 30.61.03 Platinum Group Metals 57
Project 30.61.05 Oxide Ores 58

Standards and Specifications 59
Project 30.69.01 Reference Materials 59
Project 30.69.02 Analytical Methodology 62

Environmental Controls 65
Project 30.86.01 Tailings Characterization and Control Mechanisms 65
Project 30.86.03 Water Pollution Control 67
Project 30.86.04 Air Pollution Control 71

Fluidized-Bed Combustion 74
Project 50.62.06 Fluidized Bed Combustion System 74

Mineral Development Agreements 76
Manitoba 76
New Brunswick 78
Newfoundland 78
Nova Scotia 80
Saskatchewan 80

PART B. GENERAL SERVICES AND OPERATIONS

Chemical Laboratory 81
Extractive Metallurgy Laboratory 82
Mineral Processing Laboratory 83
Industrial Research Assistance Program (IRAP) 84
Cost Recovery Contracts 85
Visiting Scientists 89
CANMET Seminar in Timmins 90

CONTENTS (Cont'd)

Page

PART C. REPRESENTATION ON TECHNICAL COMMITTEES

International 91
Canada 94
United States of America 98

PART D. PUBLICATIONS, PAPERS, PRESENTATIONS AND REPORTS

Articles and Chapters Published in Books 101
Book Reviews 101
Papers Published in Conference Proceedings 102
Papers Published in Outside Journals 104
Presentations 106
CANMET Reports (CM) 110
Special Reports (SP) 110
National Uranium Tailings Program (NUTP) 111
Division Reports 111
    Investigation Reports (IR) 111
    Technical Reports (TR) 113
    Literature Surveys (LS) 113
Patents and Applications 113
Unedited Miscellaneous Reports 114

PART E. PROFESSIONAL, TECHNICAL AND ADMINISTRATIVE STAFF

MSL Staff 119

PART A. RESEARCH AND DEVELOPMENT

MINERAL AND ENERGY TECHNOLOGY ACTIVITY

COAL MINING AND PREPARATION SUB-ACTIVITY

Coal Desulphurization

- **Project 20.79.01: High Sulphur Coal**
  Project leader : K.S. Moon

Objective:

To contribute to the technology of economically upgrading high sulphur coals to meet more stringent specifications for thermal and metallurgical coals and future requirements for coal combustion, conversion and environmental regulations.

Project Summary:

As this project will be consolidated into CANMET's Coal Research Laboratories in FY 1990/91, no new activities were initiated in FY 1988/89. A comprehensive project report is being prepared on the High Sulphur Coal Project, which will summarize the results of all activities and will indicate the direction for future R&D. The activities in the reporting period are summarized below.

(a) Magnetic separation

Clean organic macereals in coal are diamagnetic. Most of the inorganic components of coal, including all ash minerals and pyrite, are paramagnetic. Various types of high intensity high gradient (HIHG) magnetic separators have been used for the production of clean coal, including cryogenic superconducting magnetic separators (4 Tesla) for Prince, Lingan and Kipp coals by Eriez Magnetics, Allis Chalmers and Cryogenic Consultants. Typically, the cleaned coals contained 2-18% ash at 70-90% recovery of combustibles. Sulphur rejection was 55-72% and 45-71% for wet and dry magnetic separation, respectively. Dedusting of -37 μm particles resulted in improved results. Optimal size for ash removal was 1.4 x 0.6 mm. In general, the lower the throughput of the separator the higher the efficiency of separation, especially for smaller particle fractions. Due to fine dissemination of pyrite in coals the rejection of pyrite is not usually satisfactory for the particle size where magnetic separation works best.

(b) Development of CANMET sulphur-form analyser

Based on two patent-pending processes, a prototype CANMET Sulphur-Form Analyser was developed for quantitative analysis of different sulphur forms in coals through a contract with Barringer Research Limited. The sulphur-containing coal sample is heated in the presence of air to produce SO_x gas. An IR detector senses the concentration of SO_x gas as a function of time. The spectrochronogram thus obtained has multiple peaks corresponding to the contents of different sulphur forms in coal. A microprocessor converts the area under the peaks to the concentration of different sulphur forms using a deconvolution technique. It was found that the addition of non-reacting silica powder to the sample improves the resolution of the peaks as well as the reproducibility of the spectrochronograms significantly. A standard technique for the analysis procedure was developed. Software for the necessary data processing and peak deconvolution was also developed. Due to the overlap of some peaks, however, the present prototype instrument is limited for routine analysis, because it requires prior knowledge of the ratio of organic sulphur I (S_{o1}) to pyritic sulphur (S_{p2}) for the coal sample. It is known that the organic sulphur in coals from a given coal field consists of S_{o2} which is constant and S_{o1} which is directly proportional to S_{p2}. Recently, a new strategy for the sulphur-form analysis was developed to eliminate the need for the prior knowledge of constant S_{o2}. The technique analyzes several sub-samples derived from the original sample. Mathematical regression analysis is used to provide the constant value of S_{o2} from which the contents of different forms of sulphur can be calculated. This new procedure is yet to be tested using the prototype instrument.

Contracts:

- Reqn. 5-9129, "Development of CANMET Sulphur-Form Analyser"; Barringer Research Limited, Toronto. S.A. - K.S. Moon.

- Reqn. 4-9164, "Dry magnetic separation of eastern coals"; Cryogenic Consultants Ltd., U.K. S.A. - G.I. Mathieu.

Reports/Publications:

- Moon, K.S., "Characterization of sulphur in coal"; MSL 89-11 (IR); August 1988.

Seminars/Conferences:

- Moon, K.S. and Sirois, L.L., "Theory and application of column flotation in Canada"; International Symposium on Column Flotation; Denver, Colorado; January 1989.

- Moon, K.S., "Physical desulphurization of coal"; Seminar, Dept. of Materials Science and Mineral Engineering; Univ. of California at Berkeley; January 1989.

MINERAL PROCESSING SUB-ACTIVITY

Minerals Evaluation

- **Project 30.05.02: Mineralogical Evaluation of Process Products**
  Project leader : W. Petruk

Objective:

To determine mineral behaviour during processing, by examination of feed and products, in order to define the conditions that grinding circuits, concentrators, hydrometallurgical and pyrometallurgical processes must achieve to obtain optimum metal recoveries, and where warranted, to recommend improvements to design and/or operation procedures of mills and processing units.

(a) Liberation flotation models

To develop a liberation model which predicts the mineral liberation that would be obtained at different grinds of different ore types, and to incorporate the predictive model into grinding and flotation models developed at CANMET by the SPOC program.

A study was conducted on the base metal ore from the Brunswick No. 12 deposit. It was found that the ore breakage and mineral liberation are strongly influenced by the behaviour of pyrite, the hardest major mineral in the ore. Initial grinding (equivalent to mill circuit discharge) broke poorly bonded pyrite grains along grain boundaries, and represents the limit of easy breakage for the ore (Petruk, 1988). It is interpreted that the initial grind liberates both large discrete grains of ore minerals and poorly bonded large grains that occur in interstices, but does not separate moderately bonded mineral grains nor release moderately bonded interstitial minerals from pyrite. Further grinding (equivalent to regrind in commercial mills) separates most of the pyrite grains from each other and releases most of the interstitial minerals from between pyrite. Still further grinding produces random breakage and liberates encapsulated grains. This last grinding stage is very energy intensive because the hard mineral (pyrite) does not have directions for easy breakage.

(b) Incorporation of mineralogical evaluations into liberation SPOC-type model

Evaluation of quantitative mineralogical analyses requires a materials balance on the quantitative mineral data, such as quantities of liberated particles. Currently, materials balance has been carried out by the MATBAL and BILMAT programs as a separate step. Preliminary work has been done to adapt the BILMAT program so that the mineralogical analysis and evaluation can be carried out in one step.

(c) Characteristics that affect recoveries from the Zn-Pb ores from the Faro deposit in Yukon

A major study of the ores from the Faro and Van Gorda deposits in Yukon has been undertaken to determine the mineralogical factors that affect zinc, lead, silver and gold recoveries in the Faro concentrator. A preliminary study was carried out by bench test on ore taken from the rod mill feed in October 1986. The bench test obtained recoveries of 82% Pb and 74% Zn, in concentrates grading 54 wt % Pb and 52 wt % Zn respectively. Evaluations of image data for the bench test products indicate that all the recoverable galena in the ore is recovered in the bench test. The company recovers about 80% Pb in a concentrate grading 50-55% Pb. In contrast, evaluations for sphalerite indicate that 85% of the sphalerite in the ore is recoverable, but at a regrind of 80% -37 μm. The current regrind used by the company is around 80% -50 μm, and the current zinc recovery is around 80% in a concentrate grading 52 to 55 wt % Zn.

A complete suite of samples was collected from the concentrator in August 1987, and liberations of sphalerite, galena, chalcopyrite and pyrite have been determined for samples from the lead flotation, zinc flotation and grinding circuit. The results are being evaluated by the BILMAT technique. Determination of the silver- and gold-bearing minerals is on-going.

(d) Commissioning of second image analyser

A second image analyser, interfaced to the JEOL 733 microprobe, has been commissioned to carry out several basic functions. Mineral type, mineral quantities and mineral liberation data can be obtained. Additional development work will be carried out for further processing of data in order to extract more information useful to the mineral processing industry. The system has been used to carry out two cost recovery investigations: one to characterize the mineralogy and gold occurrence in a refractory concentrate, and the other to predict liberation in a Cu-Zn mill feed.

Publications:

- Petruk, W., "Predicting mineral liberations in ores and mill products and effect of mineral textures and grinding methods on mineral liberation"; Processing Mineralogy VI, AIME; New York; 1987.

- Petruk, W., "Ore characteristics that affect breakage and mineral liberation during grinding"; Processing Mineralogy VIII, AIME/TMS; pp. 181-193; Warrendale, PA; 1988.

Contracts:

- Reqn. 4-9232, "Mineralogical studies of potash deposits"; New Brunswick Research and Productivity Council. S.A. - W. Petruk.

- Reqn. 4-9235 MDA, "To determine mineralogical characteristics that affect the behaviour of copper, zinc, lead, silver and gold in copper, zinc and lead concentrates from Cu/Zn/Pb ores in Manitoba, Phase (1a) mineralogical characteristics of Trout Lake ore, Phase (1b) behaviour of Trout Lake ore during beneficiation"; Hudson Bay Mining and Smelting Co. S.A. - W. Petruk.

- **Project 30.05.03: Mineralogical Characterization of Ores**
  Project leader : L.J. Cabri

Objective:

To assist in the development and processing of Canadian mineral resources including various tonnage, low grade and complex deposits of metallic minerals and industrial mineral occurrences by assessment of the mineralogy, valuable element distribution, and probable liberation characteristics directed toward the improved recovery of the contained minerals.

(a) A cost-shared, cost-recovery agreement was signed with Galactic Resources Ltd., Vancouver, to carry out further detailed mineralogical assessment of samples from the Wellgreen property, Yukon. The drill-core samples arrived just before the end of 1988 and work has begun. This is an addition to an earlier cost-shared, cost-recovery agreement with Archer, Cathro & Associates, Vancouver, on the same Cu-Ni-Pt-Pd property. Part of this study includes proton microprobe analyses at the University of Guelph of the sulphides to determine the concentration of platinum-group elements invisibly contained as a solid solution.

(b) A second cost-shared, cost-recovery agreement was signed with the B.C. Ministry of Energy, Mines and Petroleum Resources, Victoria, to do further electron microprobe analysis of complex platinum-group minerals (PGM) from B.C. The previous contract had demonstrated the complexity of the PGM but had also provided an indication of the provenance of platinum nuggets from placers in the Tulameen area, with direct implications for exploration.

(c) A very rare rhenium sulphide from the platinum-group bearing Coldwell complex, Ontario, was analyzed in a collaboration with Lakehead University. The results have been written up for publication.

(d) Despite delays in implementing the full quantitative-analysis aspect of the X-ray Automated Powder Diffractometer, the qualitative analysis is working very well. Mineral identification, as well as precise cell-dimension refinement from the powder-pattern, are now done regularly. Where previously the Debye-Scherrer X-ray powder camera was the basic tool in the X-ray laboratory, this has now been superceded by the powder-diffractometer. Two video terminals are now connected to the computer, which runs the software and controls the hardware, and both are fully utilized. In addition, the JCPDS library of X-ray powder-pattern standards is now on hand on a CD-ROM disk, connected to the laboratory's PC.

Searches for patterns matching an observed pattern can now be carried out either on-line (on the APD computer) or off-line (on the lab's PC). Boolean searches, for matching lines, or chemistry, or combinations of the two, can also be done. The microdiffractometer, capable of examining samples as small as 5 micrograms, has finally been brought on-line, and work over the next year will focus on turning it into a routine operational tool.

Contracts:

- Reqn. 8-9057, "To obtain trace element analyses of selected minerals using the proton microprobe and PIXE analysis program for thick targets"; University of Guelph. S.A. - L.J. Cabri.

Reports:

- Cabri, L.J., "Overview of application of platinum mineralogy to mineral exploration and processing"; Process Mineralogy VIII, AIME/TMS (in press).
- Cabri, L.J. and Laflamme, J.H.G., "Mineralogical study of the platinum-group element distribution and associated minerals from three stratigraphic layers, Bird River Sill, Manitoba"; CANMET Report 88-1E.
- Scoates, R.F.G., Eckstrand, D.R. and Cabri, L.J., "Interelement correlation, stratigraphic variation and distribution of PGE in the Ultramafic Series of the Bird River Sill, Canada"; Geo Platinum '87; 239-252.
- Mitchell, R.H., Laflamme, J.H.G. and Cabri, L.J., "Rhenium sulphide from the Coldwell Complex, northwestern Ontario, Canada"; Mineral. Mag. (in press).
- Hulbert, L.J., Duke, J.M., Eckstrand, D.R., Lydon, J.W., Scoates, R.F.G., Cabri, L.J. and Irvine, T.N., "Geological environment of the platinum-group elements"; Geological Survey of Canada; Open file report 1440.
- Cabri, L.J., Craigen, W.J.S., Pouskouleli, G. and Stemerowicz, A.E., "Platinum metal recovery"; MSL Report 88-148 (IR).

Beneficiation - Metallic

- **Project 30.13.01: Computer Aided Mineral Processing (CAMP)**
  Project leader : D. Laguitton

Objective:

To provide the technology transfer necessary to improve the recovery and/or value of minerals from the processing of Canadian ores through the application of modelling and simulation of minerals and energy processes, by providing the mineral industry with an easily usable computer methodology for circuit evaluation and optimization.

Project Report:

In 1988/89, activities remained focussed on two parallel areas:

1. Conventional computer aids for mineral process evaluation and optimization;
2. Expert systems prototyping in mineral processing.

A significant milestone in the development of mineral processing software at CANMET was met with the announcement of a new release of software at the First Canadian Conference on Computer Applications in the Mineral Industry (CAMI) held in Quebec City in March 1988. The first industrial acquisitions were used as test cases to improve user interfaces and correct errors. As a result, requests for the latest version of the material balance algorithm MATBAL by organizations in Canada and abroad have undergone a new surge. A new, highly interactive version of the RTD program for residence time distribution modelling was developed with the option of calibrating existing RTD data or simulating a user selected tank in series model. The screen management software developed to enhance the CAMP software user interfaces was instrumental in upgrading all programs. As a recognitions of its originality and usefulness, a paper describing these programming aids was accepted for publication in the prestigious Computer Journal. Work progressed on a generalized plant simulator in which most unit simulators available in the UNISIM package are callable as well as user defined modules. The gold leaching option of BILMAT, a powerful material balance algorithm, was made operational in the latest PC version that shows a drastic improvement over previous releases: mass balance equations for all subnetworks are automatically generated after the flowsheet is drawn on the screen and the experimental data is entered.

The assessment of expert system technology initiated in 1986-87 was successfully pursued in 1988-89.

The main activity consisted in a cooperative research project jointly funded by CANMET and Kidd Creek Mines to develop an expert system for on-line data validation and substitution in the XRF sampling system of the Cu-Zn flotation plants. The NEXPERT development shell was selected largely because of the portability claimed by the manufacturer, allowing development on MAC-II and PC computers and delivery on Microvax. Delays were encountered due to failure of NEXPERT 1.0 to perform as expected. Version 1.1 resolved most problems and on-line connection is being tested at writing time (Feb. 1989).

Contracts:

- Reqn. 7-9214, "Development of an expert system for process control in a flotation plant"; Falconbridge Ltd. Kidd Creek Mines Div. S.A. - D. Laguitton.

Reports:

- Burrows, M., Carriere, J., Leung, J. and Laguitton, D., "An expert system to improve reliability of assay information in a flotation plant"; Proceedings of the 20th Conference of the Canadian Mineral Processors Division of the CIM; Ottawa; January 1988.
- Bilodeau, M., Ter Heijden, E. and Laguitton, D., "CRSHEX: A computer program for crushing plant simulation"; (users guide); CANMET Division Report MSL 89-3 (TR).
- Cimon, D. and Laguitton, D., "BILMAT on microcomputers: A powerful material balance algorithm in a user-friendly environment"; CANMET Division Report MSL 89-6 (OP&J).

- **Project 30.13.02: Iron Ore Processing**
  Project leader : W.H. Cameron

Objective:

To maintain the viability and competitiveness of the Canadian iron ore industry by identifying and investigating methods to increase recovery, improve grade and quality of ore concentrates and pellets, reduce energy costs, improve process control and lessen environmental impact.

It has become increasingly apparent in an iron ore buyer's market that Canada cannot assume it can compete in any market. High labour and energy costs have made pellets less attractive than sinter feed for a blast-furnace. The Canadian iron ore industry finds itself in a position which is less competitive than formerly. There is a need to improve efficiency, reduce energy costs and improve product quality and recovery.

(a) Mill recovery predictions from blast-hole cuttings

Several techniques have been assessed to resolve this problem including elutriation, magnetic separation and knelson bowl classification. None have been able to give as accurate results as tabling or heavy liquid separation. There is hope that a down-the-hole analyzer, jointly being developed by the G.S.C. and CANMET may show some promise.

(b) Enhanced dewatering of O.C.M. iron ore concentrate

Nine series of laboratory scale filtration tests were carried out. Investigated were the influence of low temperature steam (110°C) and two different agents to lower the surface tension of the water. Results, although quite preliminary, seem to be promising. The moisture in the concentrate could be lowered by 1% in comparison with the standard sample.

(c) Wabush rougher spiral tailings

An investigation into producing an acceptable iron ore concentrate from Wabush rougher spiral tailings was done using reverse flotation followed by magnetic separation. The target set for the final concentrate was 65% Fe at a minimum recovery of 80% with less than 1.0% Mn and less than 2% SiO_2. A final concentrate was produced containing 64.10% Fe at a recovery of 76.7% Fe, 1.23% Mn and 0.69% SiO_2. It was felt that Mn in the concentrate was in solid solution and no further work was done.

(d) Iron ore recovery of Wabush mines

The third phase of this contract, carried out under the Canada/Newfoundland MDA, has been completed in pilot plant tests. Although no final results are available yet, preliminary results are encouraging. Phase IV, flowsheet optimization, will soon begin with most of the work being completed by March 31, 1989.

(e) Bass River magnetite

This project, conducted as a contract under the Canada/Nova Scotia MDA, has been successfully completed resulting in a high grade magnetite suitable for coal washing and possibly as a paint pigment. It is the contractors intention, dependent upon financing, to open a small mine at the Bass River location in Nova Scotia.

(f) Circuitry instrumentation and process control

CANMET, at the request of four major iron ore producers, has been negotiating with the producers and two major equipment suppliers in order to upgrade CANMET's pilot plant to "state of the art" by adding new instrumentation and process control. CANMET would then operate the pilot plant for the benefit of the industries to develop and optimize new or existing flowsheets. Several proposals have been made, the final of which was accepted by two of the four producers with some hope that a third may yet participate. This project is to be carried out over a period of three years. A 60 cm test mill which may be run fully or semi-autogenously has been ordered to be used in conjunction with the project.

(g) Other activities

Two meetings of the Iron Ore Technical Task Force Committee were held in Labrador City, on September 28, 1988 and in Ottawa on January 20, 1989. An ad hoc Committee Meeting on Circuitry Instrumentation and Process Control was held at the Adams Mine, Kirkland Lake, June 8, 1988.

Contracts:

- Reqn. 7-9174 MDA, "To improve iron ore recovery at the Scully Mine"; Labrador, Phase IV. S.A. - M. Stefanski.

- Reqn. 6-9171 MDA, "Evaluation of the Bass River, Nova Scotia, magnetite deposits, Lodestone Limited". S.A. - W.H. Cameron.

Outside Contract Activities:

- Industrial Research Assistance Program of the National Research Council - Arrangement No. CA 103-7-1202, "Improved iron recovery" at Iron Ore Company of Canada. S.A. - W.H. Cameron.
- Natural Sciences and Engineering Research Council - Project No. CRD-8709, "Optimizing sinter quality and productivity using specular hematite concentrates in Canadian sinter mines". Liaison Officer - W.H. Cameron.

Reports:

- Cameron, W.H. and Reynolds, V.G., "Investigation to produce an iron concentrate of low manganese content from Wabush rougher spiral tailings"; Division Report MSL 88-39 (IR).
- Stefanski, M.J., "Circuitry instrumentation and process control"; Division Report MSL 88-112 (LS).

• Project 30.13.07: Beneficiation of Complex and Refractory Ores
Project leader : T. Cienski

Objective:

To develop new process and treatment methods for the beneficiation of complex and refractory ores.

It has become increasingly apparent that many high grade and easily liberated ores are being depleted. In order for Canadian mining operations to remain competitive on a world market, it is necessary to develop methods to efficiently treat complex, low grade and refractory ores.

(a) Tally Pond

Work on the Tally Pond north zone resulted in a copper concentrate with 26% copper at a recovery of 90% with a zinc content of 1.1%. This concentrate was judged to be optimum for this ore. Head sample assayed 5.27% Cu, 3.35% Zn and 0.29% Pb. It was not possible to produce a high grade zinc concentrate. The highest grade produced assayed 50.7% zinc which is equivalent to only a 79% zinc sulphide grade.

On the southeast and south zone ore samples, copper grades and recoveries were appreciably lower. On the other hand, a zinc concentrate assaying 59.9% zinc was achieved on one sample from the southeast zone.

(b) Faro Deposit - Curragh Resources

The ore did not prove as difficult to concentrate as was anticipated. A lead rougher concentrate was upgraded from 18.5% to an acceptable 54.2% concentrate after three stages of cleaning with a recovery of 83% based on lead in the feed or 93.6% based on lead in the rougher concentrate.

The zinc rougher concentrate was upgraded to a satisfactory grade of 52.8% Zn with a recovery of 74.8% based on zinc in the feed or 92.9% based on zinc in the rougher concentrate. It is believed higher lead concentrates could be attained with additional cleaning and higher zinc concentrates if the zinc rougher were reground.

(c) Kidd Creek "C" ore

A preliminary investigation was carried out on a sample of Kidd Creek "C" ore assaying 0.49% Cu, 1.70% Pb, 9.20% Zn and 25.73 g/t Ag. A 47.4% lead concentrate grade with a 62.8% lead recovery and a zinc concentrate grade of 56.2% zinc concentrate with a 85.3% zinc recovery was produced. Total silver recovery in the pregnant solution and lead and zinc concentrates was 80.1%. Continuation of the investigation which would include a quantitative mineralogical study of the ore and test products is suggested.

(d) HBMS Trout Lake ore

Three preliminary flotation tests were carried out on this ore. A copper concentrate assaying 16.1% Cu at a recovery of 90.8% and a zinc concentrate assaying 51.7% zinc at a recovery of 76.5% were achieved. Separation efficiency was 79.9%. Further studies by sequestering with a chelating agent are recommended.

(e) Tin flotation using newly developed reagents

Investigation continued this year to upgrade a flotation tin concentrate obtained by using a Birquest reagent.

Sulphide flotation was performed prior to tin recovery. Over 85% of the sulphur carriers were removed. This was followed by the rougher flotation and by a number of cleaning stages, with and without regrinding. The rougher concentrate of 0.6% Sn was upgraded to 5% Sn. Further investigations are in progress.

(f) Column flotation

A pilot plant size, fully computerized flotation column (6.1 cm diam. x 674 cm/h) has been purchased, installed and commissioned. various trial runs were performed on a variety of base metal ores and on a chromite ore. The flotation column is in considerable demand for cost recovery projects.

A joint CANMET-industry-university column flotation research program is being prepared. The purpose of this program is to reach a better understanding of column fundamentals and the capabilities of this technology and to develop control strategies.

Outside Contract Activities:

- Natural Sciences and Engineering Research Council - Project No. CRD-8636, "The action of grinding additives on cement clinker particle surfaces". Liaison Officer - T. Cienski.
- Industrial Research Assistance Program of the National Research Council - Arrangement CA 103-8-1264, "Agitated flotation column". S.A. - T. Cienski.

Presentations:

- Cienski, T., "Column flotation testing at CANMET pilot plant"; CANMET Seminar, November 22-23, 1988, Timmins, Ontario.

Reports:

- Stemerowicz, A.I. and Leigh, G.W., "Final report on the concentration of Tally pond massive sulphide ores from Buchans area, Newfoundland"; Division Report MSL 88-118 (IR).
- Stemerowicz, A.I. and Leigh, G.W., "Production of lead and zinc concentrates from the Faro deposit of Curragh Resources Corporation, Yukon Territory"; Division Report MSL 88-121 (IR).
- Stemerowicz, A.I. and Leigh, G.W., "Preliminary bench-scale metallurgical investigation - Kidd Creek "C" ore"; Division Report MSL 88-151 (IR).
- Lucas, B.H. and Cristovici, M.A., "Recovery of PGM's and gold from Lac des Isles ore for Madeleine Mines Ltd."; Division Report MSL 88-9 (CR).

Beneficiation - Industrial Minerals

- **Project 30.21.01: Energy Conservation in Industrial Mineral Processing**
  Project leader : F.R. Campbell

Objective:

To increase the efficiency of energy use in the industrial minerals sector through the identification of energy intensive operations; identification, development and testing of improved technology; and transfer of that technology to industry.

(a) Comminution

A multi-phased study on Energy Conservation in industrial minerals processing was started in 1983. Phase I included studies on 10 different industrial minerals in the development of a database and unit energy consumption. This phase confirmed that the energy input, for grinding in particular, was substantial and contributed a very large proportion of product cost. Phase II involved the establishment of particle size measurement and monitoring methodology, which is critical in the search for reduction in energy costs. Phase III was to develop a pilot scale system to demonstrate the new technology for various industrial minerals. Phase III is composed of the following activities:

1. demonstration of high efficiency classifiers;
2. improved classifier;
3. grinding aids and antistatic agents;
4. process optimization using on-line particle size monitors;
5. Comparison of wet and dry milling of asbestos;
6. autogenous grinding of nepheline syenite;
7. optimization of mica grinding;
8. attrition milling of silica to make foundry sand; and
9. on-line particle size analyses and control of a cement clinker grinding circuit.

Phases I and II were completed in 1985. Six of nine activities have been completed in Phase III. Reports and seminars have been produced on activities 1, 4 and 6. A full day seminar at CANMET is to report on activities 2, 3 and 5.

Activities 7 and 8 will not be done because there is a lack of interest by the industrial minerals-producing companies. There is only one mica producer in Canada at present, and that company wished to retain confidentiality of practice. There is potential to interest a company in the activity 8, but the potential profit margin in producing 100,000 tonnes per year of product is diminishing because of a very strong U.S. producer. Activity 9 may not proceed because there are technical problems with on-line particle size measurement, and the cost of implementation in a cement plant was estimated by Canada Cement Lafarge to be $10 million, a cost judged by the company to be too high, even with partial funding from other sources.

Some difficulty is being experienced in completing this project because of the closing of a major contractor, Witteck Development.

(b) Fluoride emission control from clay kilns

The objective of this project was to determine and demonstrate the feasibility of controlling fugitive fluoride emissions in brick manufacture. There had been concerns expressed by the Canadian Clay Brick Manufacturer's Association that external scrubbers are too costly and significantly reduce tunnel kiln operating efficiency.

The approach was to identify the fluoride-containing species in the raw materials and develop methods to complex the fluoride and trap it in the bricks. During the past year, scanning electron microscopy and microprobe results showed that the fluoride is associated with a portion of the calcium silicate in the brick composition. This was reported to the Clay Brick

Manufacturer's Association, along with a proposal to do work on a sponsored basis on control of the fluoride emissions.

Contracts:

- Reqn. 4-9263, "Energy conservation in comminution of industrial minerals, Phase III: Development of pilot plant systems"; Canada Cement Lafarge Ltd. S.A. - T. Cienski.

- **Project 30.21.02: Beneficiation/Grinding Studies of Industrial Minerals**
  Project leader : D.G. Feasby

Objective:

To continue to identify problems and opportunities, and to develop and improve processing methods for the recovery of minerals and metal products acceptable to specific markets from selected mineral deposits, including improved methods for the production and classification of ultra-fine minerals for specific applications, notably the filler/extender market: to provide comprehensive technical reviews on industrial minerals processing.

Activities:

Summary reports were completed on barite, celestite, fluorite and silica in 1988. Summary reports are in progress on mica and graphite and gypsum. These reports, which summarized the beneficiation studies at CANMET in previous years, and the current industrial activity in Canada in these particular minerals, are proving to be very much in demand by industry. Several small beneficiation studies were conducted for a variety of industrial and provincial government clients. These minerals were sillimanite, kaolin, wollastonite, graphite, garnet, kyanite and zircon. Zircon is currently in short supply and the price to Canadian consumers has risen sharply. A sample provided by Syncrude was examined for zircon content, but a proposed shared-cost program with the company did not develop because the zircon content proved to be too low and the minerals too fine for the market. A sample of heavy beach sands collected by the Pacific Geoscience Centre from the northern rim of the Queen Charlotte Islands proved to have significant heavy mineral content.

Pilot-scale tests were completed on the grinding and flotation testing of Bakertalc ore, and on Bird River chromite in support of the Manitoba Mineral Development Agreement.

The concept of a regional custom grinding and classification plant for industrial minerals continues to generate commercial interest; meetings were held in Quebec and discussions were held with representatives from British Columbia.

During 1988/89, the amount of unsponsored work declined substantially, and beneficiation work was mostly done on a cost recovery basis.

Contracts:

- Reqn. 6-9163 MDA, "Preparation and evaluation of certain N.S. industrial minerals for use in filler, extenders and chemicals"; Magstone Development. S.A. - R.K. Collings.

  This work showed that two deposits had very good potential. Unfortunately, the original contractor, died before completing the work (completed by R.K. Collings), and implementation would need other commercial interest.

- Reqn. 7-9047 MDA, "Evaluation of the production of potassium phosphate fertilizer in eastern Canada"; Kilborn Ltd. S.A. - D.G. Feasby.

  Economic production is feasible but there is no known commercial interest.

- Reqn. 7-9035 MDA, "Use of anhydrite in cementitious products"; Technical University of Nova Scotia. S.A. - D.G. Feasby.

  Results are very positive. A new industry is expected to develop using N.S. anhydrite as mine support in coal mines. A large in situ test is being delayed by a strike at DEVCO.

- Reqn. 6-9147 MDA, "Prefeasibility study on the economics of Bird River chromite deposits"; Hatch Associates. S.A. - P.R.A. Andrews.

  Results indicate that if the supply of chrome ore from southern Africa became tight, the Bird River deposit would be very suitable as a chromium supply. However, even without supply restrictions, the deposit is suitable for high chromium stainless steel and chromium chemicals production.

- Reqn. 7-9189 MDA, "Dense media separation of potash ore"; Cominco Fertilizers (cost-shared). S.A. - D.G. Feasby.

  A Triflow separator was tested and shown capable of efficiently separating potash from salt at a coarse size. This technology will be implemented by the companies when demand for potash exceeds current capacity.

- Reqn. 7-9226 MDA, "Dry magnetic separation of potash ore"; Central Canada Potash (cost-shared). S.A. - D.G. Feasby.

  Results show technical feasibility, but not yet economic because of capacity limitations.

- Reqn. 7-9221, "Offshore product quality, Phase II"; Kalium Chemicals (cost-shared). S.A. - D.G. Feasby.

  Developed measures to measure and control the deterioration of potash in transit.

- Reqn. 7-9177, "Mechanochemical grinding of industrial mineral fillers"; Ontario Research Foundation. S.A. - P.R.A. Andrews.

Contracts in Progress:

- Reqn. 7-9005 MDA, "Study of the production of barium chemicals for the Lake Ainslie Barite Deposit". S.A. - D.G. Feasby.
- Reqn. 7-9149 MDA, "Market evaluation of the production of stainless steel and chromium chemicals". S.A. - P.R.A. Andrews.
- Reqn. 8-9173 MDA, "Potash tailings disposal" (cost-shared). S.A. - D.G. Feasby.

Reports:

- Andrews, P.R.A. and Kelly, W., "A preliminary study of the beneficiation of sillimanite from Clarendon, Southeastern Ontario"; Division Report MSL 87-167 (IR).
- Andrews, P.R.A., "Flotation of chromite from chromite ore obtained from Bird River, Manitoba"; Division Report MSL 88-47 (IR).
- Collings, R.K. and Andrews, P.R.A., "Beneficiation of barite"; A review of processing studies at CANMET; Division Report MSL 88-62 (IR).
- Andrews, P.R.A., "Preliminary assessment of two clay samples from New Brunswick"; Division Report MSL 88-86 (IR).
- Andrews, P.R.A., "Beneficiation of two samples of wollastonite from Marmora, Ontario"; Division Report MSL 88-89 (IR).
- Andrews, P.R.A., "Optimisation of grinding and flotation parameters, pilot plant treatment of Bakertalc ore"; Division Report MSL 88-95 (OP&J).
- Andrews, P.R.A., "Separation of graphite, biotite and micaceous minerals from a Nova Scotia garnet schist"; Division Report MSL 88-100 (IR).
- Collings, R.K. and Andrews, P.R.A., "Beneficiation studies, production and current interest of barite, celestite and fluorite ores in Canada"; Division Report MSL 87-42 (OP&J).
- Mathieu, G.I., "Historical evolution of magnetic separation"; Division Report MSL 87-164 (OP&J).

Treatment - Ceramics

- **Project 30.29.01: Preparation and Characterization of Advanced Ceramic Materials**
  Project leader : T.A. Wheat

Objective:

To develop the technology for the fabrication and exploitation of various advanced ceramics for both structural and functional applications and to demonstrate their promising applications through technology transfer.

This project is based on the growing commercial interest in both functional (e.g., electrical, magnetic, optical, etc.) and structural ceramics. Some of the functional uses are in sensors of various kinds, NDT transducers, high energy-density batteries for electric vehicles, ion pumps and fuel cells. Structural applications are based on toughened, wear-resistant, corrosion resistant and high-temperature high-strength ceramics for uses such as in gas turbines, internal combustion engine parts, heat exchangers and equipment handling corrosive and erosive material, cutting tools and contact bearings.

(a) Functional ceramics

MSL is refining a range of hydrogen-conducting solid electrolytes (Hyceram™) developed for hydrogen sensors (in-house work) and tritium-ion pumps (CANMET-AECL co-operative program at AECL). A U.S. patent was issued to CANMET in 1988 for the production of these materials.

Piezoelectric and electrostrictive materials based on a range of polycrystalline doped titanates and niobates are under development in collaboration with a Canadian manufacturer for a wide range of applications including NDT and medical sensors, ultrasonic machining and welding equipment, spark ignitors and micropositioners for robots. A number of these materials have been synthesized and the influence of the various processing and sintering parameters on the crystal/microstructure, dielectric and piezoelectric properties is being investigated.

Technical assistance is also being provided to a major manufacturer in the development of beta"-aluminas (one of the materials CANMET pioneered in Canada in the mid to late 1970's) for use in the sodium-sulphur battery currently under development for electric vehicles.

(b) Structural ceramics

MSL is working on zirconia-toughened alumina and mullite in collaboration with a structural ceramics manufacturer for applications requiring high wear resistance and/or thermal shock resistance.

Work is underway in-house for the development of non-oxide ceramics based on silicon carbide for high-temperature high-strength applications and a collaborative program with industry is underway in the development of various ceramic-ceramic reinforced composites based on this and other non-oxides.

In-house work on zirconia toughened alumina and mullite has shown the influence of various starting raw materials on the properties of the products and a technique has been developed that is available for licencing which allows the selective surface toughening of components without requiring changes to any existing forming process whether by slip-casting, extrusion or pressing and without additional capital investment.

The preparation of fine powders of zirconia of specific characteristics by a hydrothermal process is also being investigated. After the successful completion of a contract to develop zirconia toughened alumina, the Electrofuel Manufacturing Company is currently producing and testing cutting tools made of toughened ceramics.

The figure below shows the fracture surface of a silicon carbide whisker-reinforced glass composite containing a low concentration of whiskers which has been examined as part of a series of composites having various whisker loadings.

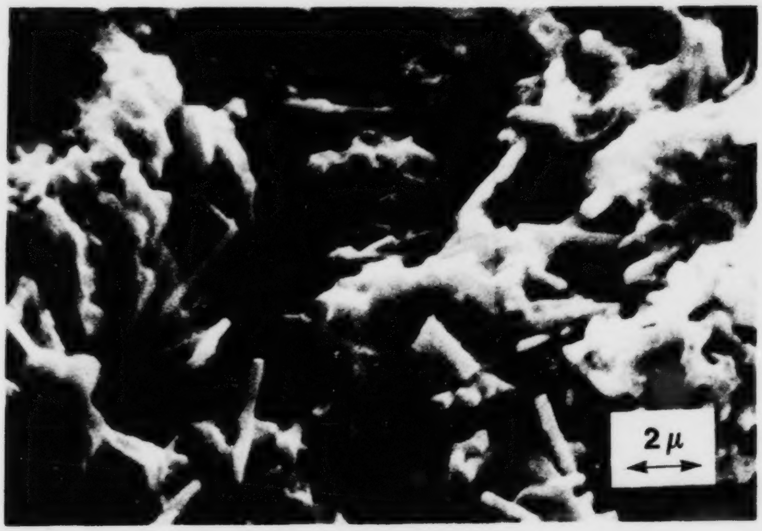


Fig. 1. SEM of a fracture surface of a silicon carbide whisker-reinforced glass composite.

(c) Technical support given other departments funding R&D in ceramics

Because of CANMET expertise, technical advice as a scientific authority has been given to various sectors of EMR, ISTC and NRC for the following contracts:

- Superionic Conduction in Bismuth Oxide	A.K. Kuriakose EMR, RAP
- Development of Beta"-alumina for Battery Applications	T.A. Wheat NRC, IRAP
- The Toughening and Strengthening of High Performance Ceramics	A.K. Kuriakose
- Hermetic Seal Technology	S.S.B. Wang NRC, IRAP
- Development of High-energy Density Battery	T.A. Wheat EMR, IERD
- Development of High Density Advanced Ceramics	T.A. Wheat NRC, IRAP
- Ceramic Powders of Controlled Morphology	T.A. Wheat NRC, IRAP
- Development of Toughened Ceramics	T.A. Wheat NRC, IRAP
- Development of Piezoelectric Materials	T.A. Wheat ISTC, DIPP
- Development of Sonar Elements	T.A. Wheat ISTC, DIPP

Contracts:

- DSS 06SQ.23440-5-9226, "Development of advanced ceramic composites based on boron nitride fibres"; The Electrical Manufacturing Company, Toronto. S.A. - T.A. Wheat.
- DSS 06SQ.23440-6-9100, "Development of tough ceramics"; The Electrofuel Manufacturing Company, Toronto. S.A. - A.K. Kuriakose.
- DSS 15SQ.23440-6-9102, "High resolution Ultrasonic transducers for non-destructive evaluation"; BM Hi-Tech Inc., Collingwood. S.A. - T.A. Wheat.
- DSS 01SQ.23440-6-9144, "Analytical interpretation of protonic solid electrolyte/electrode polarization on devices"; The Electrofuel Manufacturing Company, Toronto. S.A. - J.D. Canaday and A.K. Kuriakose.

- DSS 01SQ.23440-7-9147, "Current interrupt measurement system"; Third Wave Engineering, Ottawa. S.A. - J.D. Canaday.

- DSS 01SQ.23440-7-9023, "Impact of advanced ceramics on Canadian industry - A market respective"; MKM International, Toronto. S.A. - T.A. Wheat.

- **Project 30.29.05: Refractories for Steelmaking**
  Project leader : T.A. Wheat

Objective:

To determine the nature and mechanisms of failure of refractories encountered in the steel industry, and to report on specifications of modified or alternative materials. This project is also based on an expressed desire on the part of the steelmakers for an "independent" source of information beyond that of their suppliers, without necessarily implying a lack of confidence in the suppliers, who provide continued advice.

(a) Determination of the cause of nozzle and nozzle stopper failure

In co-operation with the Canadian Steel Foundaries Division of Hawker Siddeley Canada Inc., Montreal, Quebec, the cause of aluminosilicate refractory nozzle and aluminosilicate-graphite stopper blockage during steel casting was investigated. The thermal expansion, contraction and melting behaviour of these materials were determined using heating microscope and pyrometric cone equivalent (PCE) tests. The chemical changes occurring in the refractories in contact with molten metal and slags were identified using scanning electron microscopy, energy dispersive X-ray and X-ray diffraction. The results indicated that several characteristics of the used and new nozzle and nozzle stopper were different. Liquid phase formation was detected at the interface of the nozzle and nozzle stopper due to the formation of manganese silicates. This liquid phase interacted with the refractories to bond the two together: it is surmised that the formation of the low melting phases is due to reaction between the manganese in the molten steel, and the refractories in the nozzle.

Future Direction:

Work will continue in response to industrial requests for assistance in characterizing the performance of refractory bricks under simulated steelmaking conditions:

Outputs:

- Quon, D.H.H. and Bell, K.E., "Performance of magnesia-carbon bricks in vacuum at high temperature"; J. Can. Ceram. Soc. 56:39-44; 1987.

- Quon, D.H.H., Wang, S.S.B., Aota, J., Wheat, T.A. and Bell, K.E., "Corrosion resistance of dolomite bricks in contact with slags"; J. Can. Ceram. Soc. 57:53-59; 1988.
- Quon, D.H.H., Aota, J., Wang, S.S.B. and Hanson, A.J., "Degradation of nozzle and stopper samples submitted by the Canadian Steel Foundaries"; Division Report MSL 88-6 (TR).
- Aota, J., Quon, D.H.H. and Wang, S.S.B., "Pyrometric cone equivalents of nozzle and stopper samples submitted by the Canadian Steel Foundaries"; Division Report MSL 88-7 (TR).

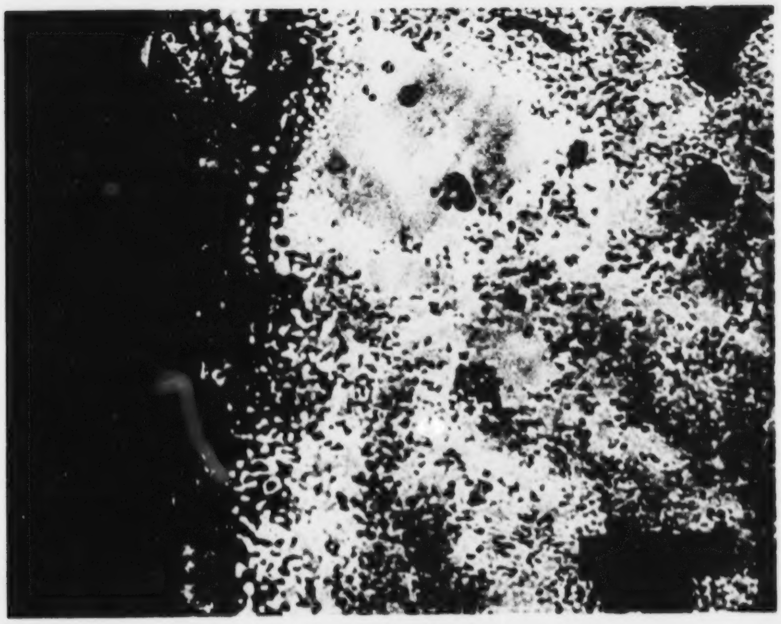


Fig. 2. SEM micrograph showing that refractory failure is due to the low temperature eutectic formed at the refractory-strontium oxide interface.

Treatment - Industrial Minerals

- **Project 30.37.01: Performance and Durability of Concrete Incorporating Supplementary Cementing Materials**
  Project leader : V.M. Malhotra

Objective:

To develop data on mechanical and elastic properties and durability of portland cement and portland cement concrete incorporating up to 65% less energy intensive materials, such as granulated blast-furnace (B.F.) slag, fly ash, silica fume and limestone dust for applications in Canada.

To conserve resources and energy it is imperative that less costly and less energy intensive materials be used in the production of portland cement and portland cement concrete. The most promising of the less energy intensive materials for replacing cement are granulated slag, fly ash and silica fume. The energy required to produce granulated slag is estimated at only 25% of that for portland cement, and fly ash and silica fume are industrial byproducts. As slag and fly ash from different sources have unique properties depending upon the raw materials used, it is essential that investigations be performed to obtain long-term performance data on their use, with and without high-range water reducers, in concrete under Canadian climatic conditions.

(a) Alkali aggregate reaction

Several investigations dealing with the alkali-aggregate reactions in concrete are in progress and several reports have been published or are being processed. Investigations dealing with the survey and evaluation of the rock types in New Brunswick, Nova Scotia and Newfoundland which may be potentially reactive are in progress, but it is too early to draw any conclusions. Several rock types which were thought to be of interest have been found to be potentially reactive.

A post-doctoral fellow commenced his duties in December, 1987 and has initiated a two-year study on the evaluation of a number of different accelerated methods for determining the alkali aggregate reactivity in concrete.

(b) High-strength concrete

Research on mechanical properties and durability of very high-strength concrete incorporating different supplementary cementing materials was continued. A judicious combination of these materials can lead to the development of concrete with compressive strength in excess of 100 MPa.

In-house investigations are continuing, including determination of long-term mechanical properties and microstructural examination of silica fume concrete. Results at ages up to 1½ year tend to confirm trends observed in preliminary investigations, i.e., different long-term strength development characteristics for this type of concrete. Strength development of high strength silica fume concrete with and without B.F. slag is being investigated in the field by testing large concrete elements cast and cured to simulate structural field applications.

A round robin test program was carried out to evaluate test methods for salt scaling resistance of concrete. Three laboratories participated, and results have indicated that the test method is relatively imprecise.

(c) High-volume fly ash concrete

Investigations were continued, both in-house and under contract to develop a data bank on the engineering and thermal properties of high-volume fly ash concrete using different cements, and different percentages of fly ash and cement contents. Test results indicate that cement factors beyond 200 kg/m^3 are not very cost effective in this system. Three large concrete blocks, 3 x 3 x 3 m in size, were cast in Halifax to monitor the long-term performance of the reference and high-volume fly ash concrete. In one investigation seven different fly ashes were incorporated into concrete at two different cement factors. The test results indicated a large difference in setting characteristics and strength properties of the resulting concretes. Long-term data collection on a massive concrete block incorporating high volumes of fly ash concrete was continued. Creep studies on high-volume fly ash concrete have been in progress and results to date indicate that this new type of concrete has relatively low creep. Also, development of engineering data on Nova Scotia fly ashes is being continued under the N.S. MDA.

(d) Activation of blast-furnace slag

Exploratory studies were commenced to identify means of activating ground granulated blast-furnace slags. The materials being investigated include sodium silicates with and without silica fume or lime. Currently, the investigation is being limited to the determination of compressive strengths on mortar cubes. If promising, the investigation will be extended to concrete.

(e) Other activities

Several investigations were undertaken as a part of "cost recovery". These dealt with the development of data on mechanical properties of fibre-reinforced high-volume fly ash shotcrete for use as a capping (sealant) for pyritic slate outcrops at Halifax airport (for Transport Canada), the development of engineering data on foam concretes (for Anthes Equipment Ltd., Toronto) and utilization of fluidized bed combustion waste as a cementitious material (for L.E. Shaw Ltd., Halifax). Testing of natural building stone was also performed.

The IRDC/CANMET project on blast-furnace slags is continuing. A scientist from INTI, Argentina spent six months at CANMET participating in investigations dealing with blast-furnace slags from Blind River, Ontario. The results indicate that concrete incorporating this slag has satisfactory mechanical properties and has excellent durability characteristics.

Contracts:

- Reqn. 8-9064, "Creep studies on high-volume fly ash concrete"; University of Calgary. S.A. - G.G. Carette.
- Reqn. 8-9171, "Development of geopolymer formulations and determination of their mechanical and durability properties for capping of pyritic slate outcrops at Halifax Airport". S.A. - V.M. Malhotra.
- Reqn. 8-9043, "State-of-the-art review on D-cracking of concrete in Manitoba"; INRAD Industrial Research and Development Ltd. S.A. - E. Douglas.
- Reqn. 4-9236 MDA, "Study of the alkali reactivity of potential concrete aggregates of New Brunswick"; ADI Ltd. S.A. - J.A. Soles.
- Reqn. 5-9255 MDA, "Study of the alkali reactivity of potential concrete aggregates of Newfoundland"; Golder Associates. S.A. - J.A. Soles.
- Reqn. 6-9157 MDA, "Study of the alkali reactivity of potential concrete aggregates of Nova Scotia"; Jacques Whitford and Associates. S.A. - J.A. Soles.
- Reqn. 7-9146, "Long-term strength development of high-strength field concrete containing silica fume and other supplementary cementing materials"; Trow Ltd. S.A. - G.G. Carette.
- Reqn. 7-9137, "Thermal properties testing of concrete incorporating supplementary cementing materials"; Geotherm Inc. S.A. - V. Sivasunderam.
- Reqn. 7-9129, "Diatomite in Nova Scotia as pozzolanic material"; W. Langley and Associates. S.A. - H.S. Wilson.

Reports:

- Malhotra, V.M., "Superplasticizers, pozzolans and granulated blast-furnace slags in concrete"; Division Report MSL 87-17 (OP&J) Draft.
- Douglas, E., Elola, A. and Malhotra, V.M., "Characterization, conduction calorimetry, microstructure and properties of ground granulated blast-furnace slag and fly ashes"; Division Report MSL 87-18 (OP&J) Draft.
- Malhotra, V.M., "Supplementary cementing materials"; CANMET Special Publications 86-6E.
- Graciela, M., Giaccio, G.M. and Malhotra, V.M., "Mechanical properties and freezing and thawing resistance of high-volume fly ash concrete made with ASTM Types I and II cements"; Division Report MSL 87-112 (OP&J) Draft.

- Sivasunderam, V., Carette, G.G. and Malhotra, V.M., "Superplasticized high-volume fly ash system to reduce temperature rise in mass concrete"; Division Report MSL 87-83 (OP&J) Draft.

- Malhotra, V.M. and Painter, K.E., "Early-age strength properties, and freezing and thawing resistance of high-volume fly ash concrete"; Division Report MSL 87-113 (OP&J) Draft.

- Malhotra, V.M., Wilson, H.S. and Painter, K.E., "Resistance of concrete incorporating silica fume at elevated temperature"; Division Report MSL 87-126 (OP&J) Draft.

- Douglas, E., Elola, A. and Malhotra, V.M., "Characteristics, conduction calorimetry, microstructure and properties of ground granulated blast-furnace slags and fly ashes"; Division Report MSL 88-18 (OP&J).

- Douglas, E. and Malhotra, V.M., "Ground granulated blast-furnace slag for mine backfill"; Division Report MSL 88-34 (OP).

- Douglas, E. and Malhotra, V.M., "Compilation of abstracts of papers from recent international conferences and symposia on condensed silica fume in concrete"; CANMET Report SP88-14E.

- Douglas, E. and Malhotra, V.M., "Compilation of abstracts and papers from recent international conferences and symposia on ferrous and non-ferrous slags in concrete"; CANMET Report SP88-13E.

- Sivasunderam, V. and Malhotra, V.M., "Compilation of abstracts and papers from recent international conferences and symposia on fly ash in concrete"; CANMET Special Publication SP87-6E; 70 pp.; 1988.

- Langley, W.S., Carette, G.G. and Malhotra, V.M., "Structural concrete incorporating high-volumes of ASTM Class F fly ash"; Division Report MSL 88-43 (OP&J).

- Soles, J.A., Malhotra, V.M. and Chen, H., "CANMET investigations of supplementary cementing materials for reducing alkali-aggregate reactions: Part I - Granulated/pelletized blast-furnace slags"; Division Report MSL 88-76 (OP&J).

- Fernandez, L. and Malhotra, V.M., "Mechanical properties, abrasion resistance and chloride permeability of concrete incorporating granulated blast-furnace slag"; Division Report MSL 88-126 (J).

- Malhotra, V.M. and Carette, G.G., "Penetration resistance methods"; Division Report MSL 88-128 (J).

- Malhotra, V.M., "Needed methodology for testing concrete repair materials"; Division Report MSL 88-144 (OP&J).

- **Project 30.37.02: Concrete for Offshore Structure**
  Project leader : V.M. Malhotra

Objective:

To develop engineering data on high strength, low permeability, and high impact resistance concrete and grouts for offshore structures; to develop concrete permeability and ice abrasion resistance and NDT monitoring inspection tests. This program is supported through the federal energy R&D program under the Panel on Energy R&D.

Oil exploration and production activities in the offshore arctic environment are expected to increase in the near future. It is anticipated that many of the offshore structures will be constructed of concrete. At present there are many unknown factors related to the performance of concrete structures in the arctic environment. The extreme cold adversely influences the properties of concrete. The ice creates additional problems of abrasion and impact. It is therefore essential that studies be performed to develop concretes which will be durable in the arctic environment. Such concrete should have high strength, low permeability and low unit weight. Also, testing methodology should be developed to determine abrasion resistance and permeability of these special concretes.

(a) Concrete durability

The yearly inspection of test prisms installed at Treat Island was performed. Visual checks were made and photographs were taken. A display and a report were prepared. About 185 visitors attending the Second Conference on the Performance of Concrete in Marine Environment, held at St. Andrews in August 1988 visited the Treat Island site to inspect CANMET specimens. A paper on this project was presented at the above conference.

Testing of concrete specimens to the combined action of ice abrasion and impact were continued by Fleet Engineering Ltd. (previously Arctec Canada Ltd.). The specimens had been prepared by CANMET and Mobil Oil Ltd., Dallas, Texas, is funding the testing of these specimens. The testing is being performed in a machine developed by CANMET and is the only one of its kind in the world. A paper on the development of the machine was presented at the conference on the Performance of Concrete in Marine Environment held at St. Andrews in August 1988.

Problems were encountered in arranging an inspection visit to Nanisivik, Baffin Island to monitor 12 high-strength concrete panels (150 x 330 x 3660-mm size) installed on the side of an existing dock at Nanisivik. A visit is being planned for 1989, and representatives of the oil industry and engineering companies engaged in offshore construction are being invited to join the inspection.

Studies were initiated to investigate the durability in a marine environment of semi-lightweight portland cement/silica fume concrete made with three different types of lightweight aggregates from sources in Canada, U.S.A. and

Germany. Large concrete prisms were cast and installed at Treat Island for long-term field exposure tests.

Work was commenced to develop permeability data of 50-mm thick concrete specimens. This size of specimen is expected to provide more efficient means of characterizing the permeability of high strength concrete.

A round robin program on air-void analysis of hardened concrete was carried out in order to develop a statistical profile of variation between different operators and different laboratories. Three different operators and three different laboratories participated in the program, and the results will be analyzed and a technical paper prepared.

Contracts:

- Reqn. 8-9065, "Durability of lightweight concrete in marine environment"; University of New Brunswick. S.A. - G.G. Carette.

- Reqn. 8-9066, "Inspection and testing of concrete test specimens at Treat Island - 1988"; University of New Brunswick. S.A. - G.G. Carette.

- Reqn. 8-9095, "Monitoring of Nanisivik concrete panels"; Université de Sherbrooke. S.A. - G.G. Carette.

- Reqn. 8-9167, "Development of permeability data on 50-mm thick concrete specimens"; Laboratoire de Béton Ltée. S.A. - G.G. Carette.

- Reqn. 6-9174, "Utilization of Newfoundland aggregates to produce high-strength concrete for offshore structures - Phase I"; Nolan Davis Ltd. S.A. - A. Bilodeau.

- Reqn. 7-9240, "Utilization of Newfoundland aggregates to produce high-strength concrete for offshore structures - Phase II"; Nolan Davis Ltd. S.A. - V.M. Malhotra.

- Reqn. 4-9041, "Reproducibility of a new technique to measure the permeability of concrete"; Laboratoire de Béton Ltée. S.A. - G.G. Carette.

- Reqn. 7-9128, "Determination of the resistance of concrete to abrasion and impact by ice: modifications to the testing machine and development additional test data - Phase II"; Arctec Canada. S.A. - V.M. Malhotra.

- Reqn. 6-9072, "Design and construction of automated freeze-thaw testing equipment for concrete"; (unsolicited proposal UP-A-470); Arctec Canada.

Reports:

- Wilson, H.S. and Malhotra, V.M., "Development of high strength lightweight concrete for structural applications"; Division Report MSL 87-11 (OP&J) Draft.

- Malhotra, V.M., "CANMET investigations in the development of high-strength lightweight concrete"; Division Report MSL 87-33 (OP&J) Draft.
- Bisaillon, A. and Malhotra, V.M., "Permeability of concrete using a uniaxial water-flow method"; Division Report MSL 87-119 (OP&J) Draft.

- **Project 30.37.03: Aggregate/Concrete Testing and Standards**
  Project leader : G.G. Carette

Objective:

To provide technical expertise and information for Canadian and international standards writing organizations concerned with aggregates and concrete, by performing development work on in-situ tests, NDT methods and other tests, by coordinating the CSA Sample Comparative Cement testing program, by organizing conferences on the use of NDT and new concrete materials and their durability, and by participating in committees of the CSA, ACI, ASTM, ISO, etc.

Aggregates, cement and concrete testing and standards contribute much to ensuring that concrete will perform as specified in construction projects, thus protecting public interest and safety.

(a) Joint comparative CSA cement sample program

At the request of the Committee on Hydraulic Cements of CSA and the Canadian cement industry, a joint project was initiated at the end of 1978 between Canadian cement testing laboratories and CANMET to assess existing cement specifications and testing methods in Canada. CANMET is coordinating the program and is in charge of the overall organization, including the preparation and distribution of test samples and the compilation, analysis and publication of test data.

Also, at the request of the above committees, CANMET has initiated a new National Cement Monitoring program for the purpose of providing the industry with a means of verifying their cement strength testing procedures. The monitor sample became available in the Fall of 1988 and is being distributed through the Canadian Certified Reference Materials Project of CANMET.

(b) Conferences, workshops and seminars

CANMET, in association with the American Concrete Institute, U.S.A., sponsored the 2nd International Conference on Performance of Concrete in Marine Environment, in August 1988 at St. Andrews-by-the-Sea, New Brunswick. The 5-day conference was very successful with more than 180 delegates from 25 different countries attending. The program covered a total of 47 technical presentations, and featured a one-day field trip to the natural weathering site of Treat Island which included inspection of on-gong field exposure test programs conducted by CANMET on the site.

The final program of the 3rd International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete has been released. The Conference which is organized and co-sponsored by CANMET will be held in June 1989 in Trondheim, Norway. About 160 technical papers will be presented and published in the conference proceedings.

The third CANMET international conference on "Superplasticizers and Other Chemical Admixtures in Concrete" is being prepared. The three-day conference will be held in Ottawa in October 1989.

A CANMET seminar on the Use of Blast-Furnace Slag, Fly Ash and Silica Fume in the Mining Industry was held in Sudbury, Ontario in September 1988. Sixty-five representatives of the Canadian mining and cement industries from private, provincial and federal laboratories attended.

Reports:

- Malhotra, V.M. and Carette, G.G., "Penetration resistance methods"; Division Report MSL 88-128 (J) Draft.
- Carette, G.G. and Bowman, W.S., "28-day compressive strength monitor cement sample CM-1"; Division Report MSL 88-80 (TR).

Biotechnology

- **Project 30.46.01: Bioprocessing**
  Project leader : R.G.L. McCready

Objective:

To identify, quantify, test and apply biological phenomena to improve mineral processes for the recovery of metal values, to enhance recovery of fossil fuels and to reduce the environmental impact of industrial operations in these fields to acceptable levels.

(a) Bacterial leaching of sulphide ores

The objective is to develop an economically viable biohydrometallurgical process to extract and recover secondary metal values from sulphide ores, specifically those portions of mineral deposits which are left underground for mine support or which are below cut-off grade for conventional mining.

Typically 30% of mineral deposits are left untouched in most mining operations. Treatment of such residual resources by bacterial leaching would enable complete utilization of ore reserves.

Projects in this area include a demonstration of commercial underground leaching of uranium and large scale pilot plant studies on the leaching of copper and zinc from a complex sulphide ore.

Contracts:

- Manitoba MDA Agreement: Hudson Bay Mining and Smelting, The University of Manitoba and Ortech International are conducting a large scale pilot plant tests on bacterial leaching of a complex sulphide ore and the recovery of copper and zinc from solution.

(b) Preferential and sequential leaching of a complex sulphide ore

The objective is to determine the rate and sequence of bioleaching of a complex sulphide ore, with a view of obtaining a better understanding of the mechanism of oxidation of metal sulphides by Thiobacillus ferrooxidans.

The sequence of leaching observed to date is pyrrhotite > cubanite > sphalerite > galena > chalcopyrite > pyrite.

Contracts:

- Reqn. 6-9126, "Determination of activity parameters in Thiobacillus ferrooxidans strains as criteria for mineral leaching efficiency"; Dept. of Microbiology, University of Manitoba. S.A. - R.G.L. McCready.

- Reqn. 8-9161, "Research study to determine the source of oxygen during bacterial oxidation of mineral sulphides"; Dept. of Physics, The University of Calgary. S.A. - R.G.L. McCready.

- Reqn. 7-9223, "Bioextraction, biorecovery and biodetoxification of metals"; Falmouth and Associates, Falmouth, ME. S.A. - R.G.L. McCready.

Fig. 3. Laboratory scale pilot plant
for biorecovery of selenium.

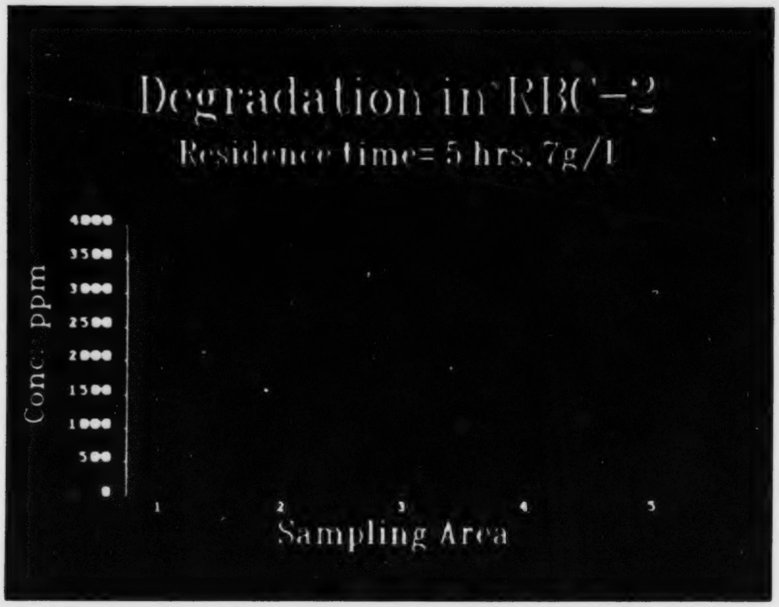


Fig. 4. Degradation of an organic pollutant in the four stages of a rotary biological contactor.

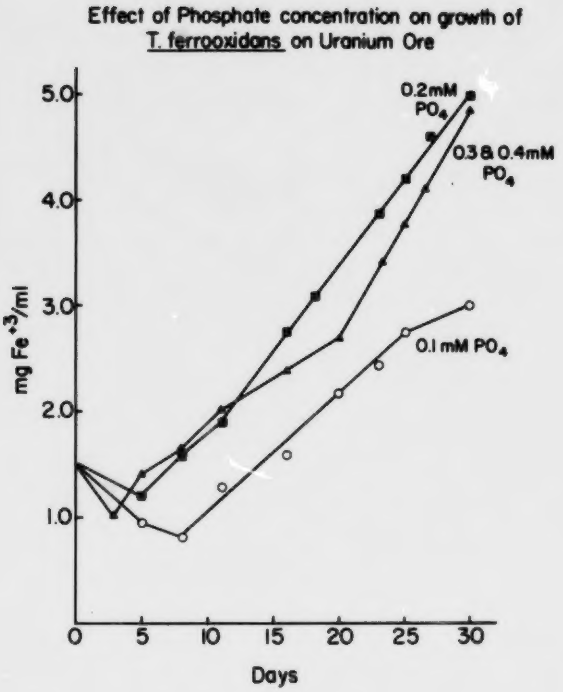


Fig. 5 - Effect of phosphate on uranium leaching by Thiobacillus ferrooxidans.

(c) Biological effluent treatment

Objective:

To identify, quantify and apply biological phenomena to mitigate the environmental degradation resulting from industrial effluents.

Projects in this area include the bioadsorption of metals from process solutions or effluents, the microbial degradation of organics which interfere with mineral recovery from ores or concentrates, the microbial recovery from mill effluents and biological mitigation of acid mine drainage. Many of these projects are carried out jointly with industry and involve confidential information.

Infrared Spectroscopy

Fourier transform infrared (FTIR) spectroscopy was used to monitor reactions and identify residues and other reaction products from a microbial process for selenium recovery.

A method was investigated for the determination of ethylene glycol in phosphate-containing solutions by attenuated total relectance FTIR spectroscopy using a CIRCLE cell. Quantitative determination of ethylene glycol alone in aqueous solution could be made using the 1045 cm^{-1} band. However, interference from a phosphate band at 1077 cm^{-1}, and also from carbohydrate and pyruvic acid spectra, rendered the method uncertain for the solutions of interest.

Contracts:

- Reqn. 7-9173, "Heavy metal removal from gold mining and tailings effluents using indigenous aquatic macrophytes"; P. Lane and Associates, Halifax, N.S. S.A. - R.G.L. McCready.

- Reqn. 7-9181, "Development of algal adsorption systems for enhanced metal recovery from mining process streams and tailings"; System Ecotechnologies Inc., Saskatoon, Sask. S.A. - R.G.L. McCready.

- Reqn. 7-9222, "Optimization of the fungal adsorption of uranium"; Ortech International, Mississauga, Ont. S.A. - R.G.L. McCready.

- Reqn. 7-9224, "Biological decarbonization of spent catalysts"; The Cambrian Engineering Group, Mississauga, Ont. S.A. - R.G.L. McCready.

- Reqn. 8-9051, "Morphological aspects of cattail transplants and microbiological aspects of organic matter in extreme acidic conditions on base metal tailings"; Boojum Research, Toronto, Ont. S.A. - R.G.L. McCready.

- Reqn. 8-9069, "Production of 1.3 kg of immobilized Rhizopus arrhizus for uranium adsorption"; McMaster University. S.A. - R.G.L. McCready.

- Reqn. 8-9082, "Loss of uranium adsorptive capacity on recycle"; McMaster University. S.A. - R.G.L. McCready.

- Reqn. 8-9156, "Design and operation of a pilot-plant on uranium bioadsorption"; Tsezos Engineering Services, Toronto, Ont. S.A. - R.G.L. McCready.

- Reqn. 8-9177, "Composting oily sludges with biomass"; Nova-Husky Research Corp., Calgary, Alta. S.A. - R.G.L. McCready.

- Reqn. 8-9198, "Development of an economic large scale growth medium for Rhizopus arrhizus, a uranium adsorbing fungus"; Ortech International, Mississauga, Ont. S.A. - R.G.L. McCready.

(d) Biotechnology in fossil fuels

Objective:

To identify, quantify and apply biological phenomena which enhance the recovery of fossil fuels or mitigate environmental damage resulting from waste disposal or processing operations.

Contracts:

- Reqn. 8-9178, "A study of bacterial plugging of "Thief" zones during oil field drilling"; Microbios Ltd., Calgary, Alta. S.A. - R.G.L. McCready.
- Reqn. 8-9186, "Biocorrosion of pipelines"; Nova-Husky Research Corp., Calgary, Alta. S.A. - R.G.L. McCready.

(e) Biotechnology networking

Objective:

On a continuing basis to maintain and expand a network to improve the interaction and communication between the research community and Canadian industry, to improve the availability and accessibility of relevant information.

BIOMINET database

The **BIOMINET** database system, which used SYSTEM 2000 on the EMR central computer facility has been converted to run on dBASE III Plus on a microcomputer. A simple menu-driven system was developed using the application generator. The former system will be retained for a year, should it be needed.

Personnel from MSL:

1. Prepared and published four **BIOMINET** Newsletters to keep members aware of current research projects and developments in the application of biotechnology in the fossil fuel and mineral industries.
2. Organized, prepared and presented a two-day workshop on "Basic Microbiology for the Fossil Fuel Industries" on November 4 and 5 in Calgary, Alberta.
3. Published the **BIOMINET** proceedings from the 1987 Annual Meeting. CANMET SP 87-10.
4. Organized and participated in the Annual **BIOMINET** meeting in Calgary on November 3, 1988.
5. Participated in the CANMET Seminar in Timmins on treatment of refractory gold ores.
6. Continue to develop the program and organize the 9th International Symposium on Biohydrometallurgy to be held in Jackson Hole, WO, August 13-18, 1989.

- **Project 30.46.03: Photoelectrochemistry of Semiconducting Minerals**
  Project leader : S.M. Ahmed

Background:

Many reactions of practical significance that take place at interfaces between semiconducting minerals and aqueous solutions are electrochemical in nature. It can be expected, therefore, that studies of electrochemical and photoelectrochemical phenomena at these interfaces will lead to means of controlling the reactions, for example, to promote leaching of ores, to inhibit oxidation and acid generation involving waste sulphides in mill tailings, or to control surface properties important in mineral separations by flotation. Also, photochemical catalytic processes on surfaces of semiconducting materials such as titanium dioxide may be harnessed to oxidize and destroy pollutants in aqueous solution.

Objective:

The objective is to investigate the role of semiconducting and other solid state properties of sulphide minerals in relation to leaching, flotation and acid generation in mill tailings, and to develop semiconducting catalysts and processes for the removal of pollutants.

(a) Photoelectrochemical studies with pyrite and chalcopyrite

Electro/photoelectrochemical studies have been carried out on chalcopyrite and pyrite to investigate the charge transfer mechanisms using redox reagents, $Fe^{3+/2+}$ and oxygen in particular. These redox reactions are directly related to chemical and bacterial leaching, and are also responsible for acid generation and secondary leaching in tailings causing acid drainage problems. The electrochemical mechanisms are not well understood, because the sulphide minerals have been assumed to behave as metals in almost all of the earlier studies.

Our recent studies have revealed strong dependence of the charge transfer properties on the energy band structure of these sulphides, the behaviour often being predictable. These studies are now being applied to prevent oxidation in order to control tailings problems, and to improve reaction kinetics where necessary to increase leaching rates.

The role of semiconducting properties of sulphide minerals in bacterial leaching and in galvanic reactions is being investigated also. The results are being applied to prevent oxidation of the mill tailings and acid generation.

(b) Industrial liaison

Negotiations have been undertaken with Noranda Technology Centre regarding studies on tailings disposal problems, and a letter of understanding has been drawn up to undertake electrochemical studies as outlined above.

Collaborative work was undertaken also with Nutech Energy Systems Inc., London, Ontario, in accordance with a letter of understanding. The work is aimed at producing a form of TiO_2 that can be used to destroy a number of pollutants, including chloro-organics such as PCBs in trace amounts.

Publications:

- Ahmed, S.M., Leduc, J. and Haller, S.F., "Photoelectrochemical and impedance characteristics of specular hematite. 1. Photoelectrochemical, parallel conductance, and trap rate studies"; J Phys Chem 92:6655-6660; 1988.
- Leduc, J. and Ahmed, S.M., "Photoelectrochemical and impedance characteristics of specular hematite. 2. Deep bulk traps in specular hematite at small alternating-current frequencies"; J Phys Chem 92:6661-6665; 1988.
- Ahmed, S.M., Leduc, J. and Trudel, J., "Studies of the field dependent photoluminescence of n-GaAs electrodes with and without cobalt films"; J Electrochem Soc 135:3015-3022; 1988.

Reports:

- Ahmed, S.M., Leduc, J. and Trudel, J., "Photoluminescence, photoelectrochemical and impedance studies of n-GaAs electrodes with and without cobalt films"; Division Report MSL 88-120 (OP&J); Presented at the 174th Meeting of the Electrochemical Society; Chicago, Illinois; October 1988.

- **Project 30.46.04: Plasma**
  Project leader : J.M. Skeaff

Objective:

The objective of this project is to investigate and develop applications of plasma technology in the fields of energy utilization and pyrometallurgy as a means of increasing energy use efficiencies and to substituting electricity for fossil fuels.

Plasma technology has the potential in many instances for the efficient substitution of electrical energy for fossil fuels utilization as well as for completely new applications. It is also evident that plasma technology has developed to the state where applications on an industrial scale are being seriously considered, are planned or are a reality. However, Canada, although possessing more than adequate supplies of relatively inexpensive electricity, lags behind the development of industrial plasma technology. To assist in the development of this technology, CANMET has undertaken to investigate potential industrial applications of plasma technology.

(a) Plasma technology in metallurgy and ceramics

Several successful iron ore reduction tests were conducted with mixtures of hematite, coke and limestone to prove out the feasibility of smelting in the 100 kVA plasma reactor, which is quiet and stable at operating temperatures under feeding conditions. The carbon and sulphur in the iron product were less than 1.0% and 0.05% respectively, although iron losses to the slag were high. In two trials conducted to smelt a chromite concentrate ($FeO \cdot Cr_2O_3$), low metal recoveries (~ 70%) were incurred and the chromium content of the metal was only 35%, which is considerably lower than the desired level of 55%. Additional problems of refractory wear and poor mass balances were also encountered. Nonetheless, a ferro-chromium alloy was produced.

Advances have recently been made in the application of thermal plasma technology in the development of new high temperature ceramic materials. These materials, which include various oxides, carbides, silicates and others, combine desirable properties such as heat, wear and corrosion resistance. Silicon carbide is considered to be one of the most promising advanced ceramic materials for potential applications in heat engines and industrial parts subject to wear. A contract on plasma synthesis of ultrafine silicon carbide powder for use in fabricating ceramic parts is currently in progress at the University of Sherbrooke, Quebec. Under this contract, a non-transferred d.c. plasma torch and reactor assembly are being used to produce SiC samples. An investigation into the production of titanium silicides and titanium-iron-silicides is also underway at Queen's University. A contract to investigate a process for the direct smelting of sulphide ores to produce elemental sulphur has also been completed.

Future Direction:

The experimental aspect of this project will conclude in 1989/90 with trials on the production of ferro-vanadium and the completion of a final report on the project.

Contracts:

- Reqn. 7-9180, "Plasma synthesis of ultrafine silicon carbide powders"; M. Boulos, University of Sherbrooke. S.A. - S.A. Mikhail.

- Reqn. 7-9196, "Plasma production of titanium silicides and titanium-iron-silicides"; C. Pickles, Queen's University. S.A. - C.A. Hamer.

- Reqn. 6-9189, "Investigation into the feasibility of direct reduction and smelting of sulphide ores in an LB furnace"; W.K. Lu, McMaster University; Hamilton, Ont. S.A. - J.M. Skeaff (completed).

(b) N.R.C. contribution arrangement

- Reqn. 5-0870, "D.C. plasma arc furnace"; Y. Okita, INCO Ltd., Toronto, Ont. S.A. - J.M. Skeaff.

Extraction - Metallics

- **Project 30.52.05: Impurities in Copper Refining**
  Project leader : J.E. Dutrizac

Objective:

In co-operation with the Canadian copper industry to develop by 1990 improved technologies for the characterization, deposition, control and processing of impurities in electrolytic copper refining.

Canada is a major producer of primary copper all of which is made by smelting. During smelting, many of the impurities contained in the copper concentrates are collected in the blister copper smelter product. It is necessary to remove such impurity elements both to meet market requirements for copper conductivity and to recuperate valuable by-products. Electrorefining in a $CuSO_4$-H_2SO_4 electrolyte is universally used for this purification. The issue of impurity control is of concern as it impacts directly on tankhouse operation and profitability. Most of the Ag, Au and Se form insoluble anode slimes during electrorefining. Although copper electrorefining has been carried out for over a century, much remains unknown about this process, and the problems associated with impurity elements are expected to intensify. If the Canadian smelting industry is to remain viable in the face of keen international competition, technological responses must be developed to overcome current problems.

(a) Characterization of copper anodes and anode slimes

Mineralogical and chemical investigations were carried out on anodes and anode slimes from Canada's three copper refineries. Further work on the behaviour of silver during electrorefining was done and quantitative data on Ag-Cu selenides were obtained. A new silver-bearing oxidate phase was identified in the anode slimes. The deportment of nickel in nickel-rich anodes and anode slimes was clarified, and a nickel-ferrite phase was identified. The occurrence of Cu-Ni-Sb oxide (kupferglimmer) in the anode slimes from the CCR refinery was demonstrated, and observations on the behaviour of kupferglimmer were made.

(b) Anode passivation

The effects of O_2, Ag and Se on copper anode passivation are being investigated. At a constant current density, the time to anode passivation decreases as the concentration of the impurities increases. Silver present in the anode dissolves with the copper, but is rapidly precipitated by cuprous ions to form a passivating silver layer on the surface. Also, the concentration of silver in the anode affects the relative amounts of Cu_2O and copper powder formed on the anode face.

(c) Alternate technologies

The CANMET ammoniacal pressure leaching process for the treatment of copper refinery anode slimes is being pursued. The development of new processes for the removal of nickel from anode slimes is underway and a series of nickel leaching tests has been carried out.

(d) Analytical methodology

Round robin analytical exchanges were organized with the three Canadian copper producers. Analytical problems associated with nickel in anode slimes were identified, and efforts are underway to resolve these difficulties. Ion chromatographic methods are being developed for the determination of trace constituents in copper electrolytes.

Future Direction:

Work will continue on the characterization of nickel, arsenic, gold and the platinum group elements in copper anodes and anode slimes. The factors affecting anode passivation, especially Cu_2O formation, will be investigated. Analytical methods will be developed to address the concerns arising from various round robin analytical exchanges.

Patent Application:

- Tan, K.G., Bedard, P.L. and Weatherell, C.J., "Selective ammoniacal pressure leaching process"; Can. Patent Appl. No. 5556372; January 12, 1988.

Reports:

- Chen, T.T. and Dutrizac, J.E., "The behaviour of silver during copper electrorefining"; Division Report MSL 88-12 (J) Draft.
- Chen, T.T. and Dutrizac, J.E., "Behaviour of silver during the electrorefining of copper"; Division Report MSL 88-82 (J) Draft.
- Chen, T.T. and Dutrizac, J.E., "Mineralogical characterization of anode slimes: Part 4 - Copper-nickel-antimony oxide ("kupferglimmer") in CCR anodes and anode slimes"; Division Report MSL 88-83 (J) Draft.
- Chen, T.T. and Dutrizac, J.E., "Mineralogical characterization of anode slimes: Part 5 - Nickel-rich copper anodes from the CCR division of Noranda Minerals Inc."; Division Report MSL 88-109 (J) Draft.
- Tan, K.G. and Bedard, P.L., "Systems modelling in hydrometallurgy"; Division Report MSL 88-130 (OP).

Fig. 6. A research chemist using an ion chromatograph to analyze As^{3+} and As^{5+} in commercial copper electrolyte.

- **Project 30.52.07: Nonferrous Smelter Technology**
  Project leader : W.J.S. Craigen

Objective:

Canada's nonferrous smelter industry is a major producer of nonferrous metals and a major emitter of SO_2. CANMET, in co-operation with other federal and provincial government departments and agencies, is assisting the industry in the development and implementation of new and improved technologies for smelter modernization, which will substantially reduce gaseous (SO_2) emissions while increasing the industry's productivity and international competitiveness.

Financial assistance for technology development projects is being obtained from DRIE (IRDP); federal/provincial MDA's; IRAP; NSERC and CANMET/DSS contracts. CANMET is the scientific authority on all government assisted technology development projects with the smelter industry.

(a) DRIE/IRDP projects

(i) Pyrrhotite rejection - INCO Sudbury

The INCO Sudbury pyrrhotite (Po) rejection project has been successfully completed and a final report has been written. Some follow-up work is presently being carried out. For the most part, target objectives for the SO_2/air process for Po rejection have been met. However, with the introduction of INCO's new mill rationalization scheme, implementation of the new technology for Po rejection appears unlikely, although Po rejection will still be an integral part of the new mill flowsheet. The knowledge base acquired from the testwork will improve INCO's capabilities to evaluate the alternatives for Po rejection and to select the most cost effective process.

(ii) Flash converting - INCO Sudbury

A new "flash converting" project has been initiated, with CANMET and DRIE approval, with testwork to be carried out primarily at Port Colbourne. The objective of this 5 year, $18.5 M project is to develop on a demonstration plant scale, a continuous flash converting process for bulk Ni/Cu matte, and thereby facilitate SO_2 capture by eliminating the majority of the present batch converting operations. This technology development project includes evaluation of gas cleaning techniques and methods for recycling smelter dusts, and if successful, can be readily integrated with INCO's planned (1994) smelter modernization, which is based on flash smelting of bulk Ni/Cu concentrate.

(iii) Pyrrhotite (Po) rejection - Falconbridge

The Falconbridge Po rejection project, scheduled for completion in 1991, is progressing satisfactorily. Two flowsheets have been selected for pilot scale evaluation, which employ both magnetic and flotation separation circuits (including column flotation). The objective is to decrease the Po content of the smelter feed by 20%, while holding nickel losses due to Po rejection to less than 1.5%. At present day nickel prices the cost effectiveness of Po rejection for reducing SO_2 emissions is even more dependent on improving Po separation efficiency and minimizing nickel losses. Nickel price therefore will be an important factor in the evaluation of Po rejection technology, and the extent to which it can be applied for reducing SO_2 emissions.

(iv) Increased roast - Falconbridge

The increased roast project is designed to maximize the amount of sulphur that can be removed as SO_2 from the roasters, and thereby maximize SO_2 capture by converting this relatively high strength SO_2 gas to sulphuric acid in the acid plant. To accomplish this, modifications to the roaster off-gas and gas cleaning systems have been implemented and successfully tested to handle the increased gas flows. Modifications to increase acid plant capacity have also been initiated. Copper coolers have been installed and successfully tested in one electric furnace and are presently being installed in the other. Additional coke requirements have been determined and methods to improve slag/matte heat transfer and cool furnace off-gases are being tested. In the converter aisle an on-line computer control system is being demonstrated to optimize converter operations for processing the higher grade matte resulting from the higher degree of roast.

(v) Converter slag cleaning - Falconbridge

To reduce the reduction burden on the electric furnace and facilitate the increased roast, a separate process has been developed and implemented to clean converter slag. This patentable process has been successful in improving cobalt recovery by 15% and nickel recovery by about 0.3%. Process development to minimize energy and reductant costs is continuing. Completion of the IRDP project is scheduled for 1990.

(vi) Smelter modernization, phase II - Falconbridge

An IRDP application for demonstration plant testing to determine the techno-economic feasibility of going to very high (85%) degrees of roast and thereby further increasing SO_2 capture, has been submitted by Falconbridge. The proposal has been assessed by CANMET and DRIE.

Because the project is aimed only at reducing SO_2 emissions and is unlikely to yield any return on investment, Falconbridge is seeking both federal and provincial government support for the estimated 6 year, $16 M R&D expenditure. Methods to accomplish this are presently being investigated.

(b) DRIE/EMR projects

(i) HBMS smelter modernization

HBMS has submitted a detailed financial analysis for the planned smelter modernization at Flin Flon, to justify their request for government financial assistance. Based on the HBMS submission, CANMET has carried out a techno-economic assessment of the alternatives for smelter modernization and has provided support for the HBMS proposal, which is premised on implementing the zinc pressure leach (ZPL) process for zinc, and retrofitting the copper smelter with a Noranda Reactor and an electric furnace for slag cleaning. Total capital costs for the modernization are estimated at $130 M, with a capital payback period of 6.5 to 8.1 years, based on estimated benefits of $16 M to $20 M/y. Potential additional benefits, amounting to $7.5 M to $10 M/y, could also be realized through successful technology development to produce a saleable sulphur by-product, recover gold and silver from ZPL residues and reduce zinc losses in copper concentrate. Work on the latter two is outlined under the Manitoba MDA projects.

(c) CANMET/NSERC projects

(i) Flash smelting - UBC/INCO

This two year co-operative project has been initiated to obtain a better understanding of the flash smelting process, particularly as applied to bulk Ni/Cu concentrate and to MK copper matte. Some operating problems have been encountered in the initial testwork. These have been rectified and testwork is continuing as planned. Because of delays in starting the project, steps have been taken to extend the duration to 3 years.

(ii) Zinc pressure leach modelling - UBC/Cominco

This three year co-operative project is in its final year. Progress on developing models based on the reaction mechanisms and rates predominating has been very good, and completion of this project is expected to be on schedule. Steps are being taken to initiate a new project, involving all of the major zinc producers (Cominco, Falconbridge, HBMS, Noranda), to extend the application of the model to more complex zinc concentrates, such as those from HBMS, BMS and Falconbridge (Kidd Creek).

(iii) Conversion of SO_2 to sulphur - McMaster/ESI*

This two year project is designed to provide fundamental thermodynamic and kinetic data which will assist ESI in optimizing the design and operating parameters of their patented $SO_2 \rightarrow S^\circ$ process, which they are proposing to test on a demonstration plant scale at Dofasco. Initiation of the project is awaiting NSERC approval.

For the demonstration plant testwork, the ESI proposal has been distributed to potential industry participants (Inco, Falconbridge, HBMS, Ontario Hydro, CEA) and is presently being assessed to determine what level of industry and government support can be obtained.

---

*Engineered Systems International

(d) CANMET/Manitoba MDA projects

(i) Pyrrhotite (Po) rejection - INCO Thompson

This four year project is in its final year. However, at INCO's request, project completion has been extended to December 1989. Po rejection is the only method presently being considered for reducing SO_2 emissions at Thompson. To be cost effective, it is essential that Po rejection be accomplished without excessive losses of nickel, and without detrimentally affecting the smelter operation. Investigations to date have been directed primarily to improving flotation separation efficiency and minimizing the effect of Po rejection on the smelter heat balance. Although progress has been good, there is little doubt that further work will be required after the present project is terminated, particularly if INCO is subjected to more stringent SO_2 emission regulations. Discussions have been held with INCO on possibly new shared-cost MDA projects (which could include refinery modernization), as a follow-up to the present project, subject to a renewal of the MDA agreement.

(ii) Gold/silver recovery from zinc pressure leach (ZPL) residues - HBMS

Work on gold/silver recovery from ZPL oxide residues has been completed by Sherritt Gordon and a final report evaluating the techno-economic viability of the recommended process has been published. The report indicates that gold/silver recovery from ZPL oxide residue is technically feasible and reasonably attractive, with an estimated capital payback period of 3 to 4 years.

Work on the recovery of gold and silver from ZPL sulphide residue has also been completed, and a final report evaluating the techno-economic viability of two technically feasible alternatives has been published. The two alternatives are "direct cyanidation" and a "pyrometallurgical process" developed at CANMET. The evaluation indicates that both processes are economically attractive, with capital payback periods of one to two years. Although the cyanidation process has lower capital costs, the pyrometallurgical process is simpler, has higher recoveries, lower operating costs and no environmental problems related to cyanide disposal.

This completes the CANMET/HBMS MDA project on gold/silver recovery from ZPL residues.

(iii) Metal recovery from oxide tailings - HBMS

The final report on the phase Ib studies has been issued by Sherritt Gordon. Based on the encouraging results reported in the phase Ia and Ib studies, the Sherritt proposed phase II studies have been approved, with some modifications to the work plan. The proposal calls for completion of the majority of the testwork by April 1989 with a final report on techno-economic feasibility by December 1989.

(iv) Zinc recovery from copper concentrate - HBMS

A project has been initiated to improve the Zn/Cu separation efficiency in the HBMS mill. Preliminary studies, using column flotation, are being carried out at CANMET.

(v) Noranda reactor study - HBMS

The techno-economic viability of utilizing a Noranda Reactor and electric slag cleaning furnace for copper smelter modernization at HBMS has been completed, and final reports have been issued by Noranda and Hatch Associates. The reports verify the economic attractiveness of this approach for copper smelter modernization.

(e) Miscellaneous CANMET/industry projects

(i) DC plasma arc furnace - INCO/IRAP

This three year project is scheduled for completion by April 1989. The furnace has been tested for reduction smelting of NiO, $NiCO_3$ and ESP dusts from the Copper Cliff smelter. Problems with plugging at design throughput, high electrode consumption and control of carbon levels in the product still appear to be prevalent. A final report is presently being prepared.

(ii) Sulphur/sulphide separation - Cominco

Cominco has developed a process for improving sulphur separation and recovery from sulphide bearing leach residues which could be applied at the Trail operations, but is unlikely to be applicable elsewhere. Further work on the problem is therefore still required, including methods for improving sulphur purity. Work on the project is continuing, including investigations on sulphur recovery from INCO Thompson refinery slimes.

(iii) Sulfation roast leach (SRL) process - DRIE/NB, ERS/RPC*

A contracted final report assessing the techno-economic viability of the SRL process has been issued by Bechtel. The main problem area identified is the lack of a really efficient and economically attractive method for recovering lead and silver from the leach residues. CANMET has provided comments and recommendations on the final report to DRIE/NB.

---

*Enhanced Recovery Systems, N.B. Research and Productivity Council

(iv) Metal recovery from smelter slags

CANMET has been carrying out laboratory studies to develop attractive methods to reduce metal losses (Ni, Co, Cu) in pyrometallurgical slags. Metallic iron and iron sulphide (pyrrhotite) have been used to collect the metal values in a matte phase. The effect of cooling rate on grain size and subsequent recovery by magnetic separation has been investigated. Factors affecting cobalt and nickel distribution in matte and slag phases are also being studied.

Future Direction:

CANMET will continue to work closely with the nonferrous smelter industry in the development of improved technologies for SO_2 control, with particular emphasis on co-operative CANMET/industry projects, funded through the MDA's (Manitoba, New Brunswick, Ontario) and Subsidiary Agreements on Economic Development (Quebec). CANMET will also continue to promote and support co-operative NSERC/university/industry projects related to nonferrous extraction/refinery and SO_2 control technologies.

Contracts:

- Reqn. 5-9030, "Develop sulphur reducing mineral beneficiation techniques and perform evaluation tests at the smelter"; INCO Thompson. S.A.- W.J.S. Craigen.

- Reqn. 5-9220, "Metal recovery from oxide tailings residues"; HBMS. S.A. - W.J.S. Craigen.

Reports:

- Craigen, W.J.S. et al., "Evaluation of GCM hydrocopper process for application to HBMS copper concentrates"; CANMET MSL 88-29; March 1988.

- Skeaff, J.M. and Craigen, W.J.S., "Techno-economic assessment of gold/silver recovery from ZPL residue"; CANMET MSL 88-106; August 1988.

- Craigen, W.J.S., "Techno-economic assessment of smelter modernization at HBMS, Flin Flon, Manitoba"; CANMET MSL 88-4 (CF); September 1988.

- Sherritt Gordon, "Gold/silver recovery from ZPL residue (phase III)"; January 1989 (Contract 6-9191).

- Sherritt Gordon, "Metals recovery from oxide tailings residue (phases Ia and Ib)" (Contract 5-9220); August 1988.

- Noranda, "Noranda process retrofit for HBMS"; March 1988.

- Hatch Associates, "Noranda reactor slag cleaning"; April 1988.

- INCO Sudbury, "Evaluation of SO_2/air process for pyrrhotite rejection"; June 1988.

- Bechtel, "Evaluation of SRL process"; August 1988.

- **Project 30.52.08: Zinc Processing**
  Project leader : J.E. Dutrizac

Objective:

In co-operation with the Canadian zinc industry, to develop by 1993, improved technologies for zinc leaching, iron rejection, impurity control, by-product recovery and zinc electrolysis; to improve the knowledge base of the extractive metallurgy of zinc.

Canada is the world's largest supplier of zinc concentrates and is also a major producer of refined zinc metal. Although the zinc industry is well established, many challenges remain. Improved milling and flotation practices are needed to increase zinc recoveries and to reject unwanted impurities where mineralogically possible. Impurity deportment during roasting and leaching is important both for impurity control and by-product recovery. Iron control is critical, and improved technologies for producing environmentally stable iron precipitates are needed. Zinc electrolysis is an energy intensive process, and better solution purification methods are required to ensure the continuous production of zinc at high energy efficiency. In this regard, the role of organics in zinc electrolysis requires detailed investigation. If Canada's zinc industry is to continue to flourish, improved technologies and better process understanding are required.

(a) Characterization of zinc ores and zinc plant products

A mineralogical investigation of the relationship between the trace element content of sphalerite and its flotation response has begun. The studies combined classical ore microscopy and modern micro-beam analytical instrumentation.

A mineralogical study of various zinc roaster products is in progress. Large amounts of silver have been detected as <0.5 µm grains associated with zinc oxide and zinc ferrite, Fig. 7. Significant is the observation that much of the cadmium and lead occur in the form of complex silicates, Fig. 8.

A study of zinc leach residues from the Kidd Creek plant has revealed the unusual occurrence of Ag_2Se coatings on residual sphalerite grains.

(b) Iron precipitation/control

The use of solvent extraction to remove iron from zinc processing solutions is being investigated; the concept is to extract the iron and then to strip it into a chloride medium suitable for spray drying to Fe_2O_3. An iron-bearing interphase precipitate and the carryover of chloride to the zinc sulphate solution are being investigated.

The conversion of jarosite-type compounds to hematite in a pressure reactor at 200-250 °C is being studied. The preferred conditions are $\sim$1 h at 225 °C; hematite seeding is critical to ensure rapid conversion of the jarosite. Unfortunately, all the hematite precipitates are sulphate-containing, and efforts are underway using FTIR and Mossbauer spectroscopy to determine the form of the sulphate.

(c) Zinc electrolysis

The effects of Mn^{2+}, $MgSO_4$, K_2SO_4, Na_2SO_4 and organic extractants on Zn electrowinning are being investigated using both synthetic and industrial acid zinc sulphate electrolytes. Work is nearing completion. Testwork on a cost-shared project with Kidd Creek on addition agents in zinc electrowinning was completed and a report is in preparation.

Future Direction:

The deportment of trace elements and the effect of these elements on different aspects of zinc processing will be pursued. Iron precipitation studies will focus on impurity control and the direct precipitation of Fe_2O_3. The role of "inert" elements and organics in zinc electrolysis will be investigated.

Contracts:

- Reqn. 7-9154, "Treatment of hydrometallurgical sulphur-sulphidic residues"; Cominco Ltd. S.A. - J.E. Dutrizac.

- Reqn. 8-9073, "The measurement of the solubility of oxygen in sulphuric acid leach solutions under pressure leach solutions under pressure leach conditions"; Prof. W. Hayduk, University of Ottawa. S.A. - K.G. Tan.

- Reqn. 5-9220 MDA, "Metal recovery oxide residues"; Hudson Bay Mining and Smelting Co. Ltd. S.A. - W.J.S. Craigen.

- Reqn. 6-9191, "Gold-silver recovery from zinc pressure leach residues - Phase III"; Hudson Bay Mining and Smelting Co. Ltd. S.A. - W.J.S. Craigen.

Reports:

- Dutrizac, J.E. and Chen, T.T., "Mineralogical characterization of silver flotation concentrates made from zinc leach residues"; Division Report MSL 88-21 (J) Draft.

- Dutrizac, J.E., "The hydrothermal conversion of jarosite-type compounds to hematite"; Division Report MSL 88-142 (J) Draft.

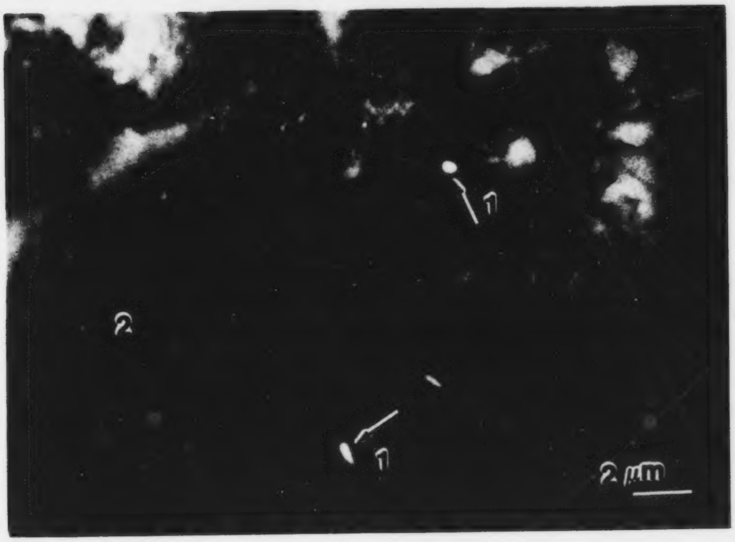


Fig. 7. Tiny grains of metallic silver (phase 1) associated with zinc ferrite (phase 2) in Kidd Creek roaster calcine.

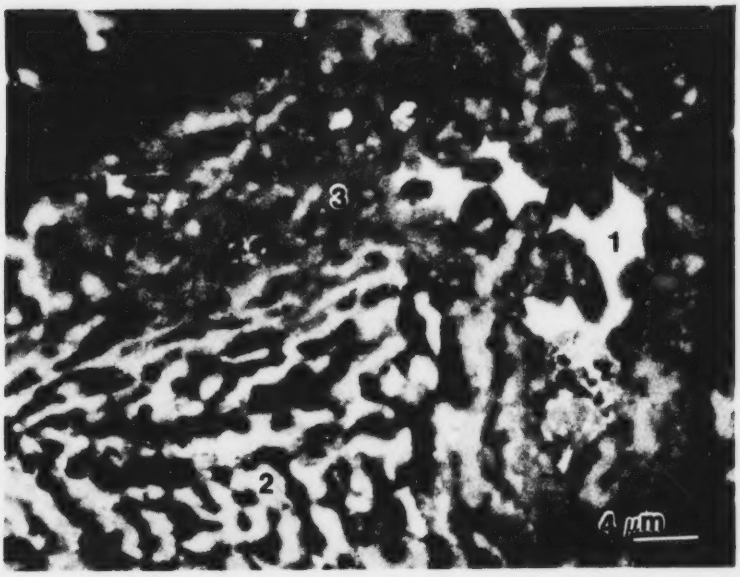


Fig. 8. Lead-zinc-cadmium silicate (phase 1) associated with zinc silicate (phase 3) and zinc oxide (phase 2) in Kidd Creek roaster calcine.

- **Project 30.52.09: Chloride Metallurgy**
  Project leader : D.H. Bell

Objective:

To develop and evaluate viable chloride metallurgical processes which will achieve the goals of metal recoveries above 90% and the elimination of SO_2 emissions by yielding elemental sulphur or stable sulphides from bulk sulphide concentrates.

Although New Brunswick has the largest reserves of zinc, lead and silver in Canada, the complexity of these sulphide orebodies has resulted in inefficient recovery of high-value saleable products using existing technology. To improve metal extraction efficiency it is necessary to produce a bulk concentrate, however, because of the complexity and relatively low grade of the bulk concentrate, it is not amenable to treatment by conventional processing technology.

Current activities relate to the development of process steps in the ferric chloride leach process, to studies of the electrowinning of copper from aqueous chloride electrolytes and to studies of dissolution rate of metallic sulphides in chloride and sulphate media.

Increasing concern over "acid rain" may in the future result in the enforcement of SO_2 emission-limiting regulations. Processes which yield elemental sulphur instead of SO_2 are potentially viable alternatives to conventional technology. Chloride technology offers such a process, however industrial acceptance will be predicated on the demonstration of technical and economical viability.

CANMET has been investigating and evaluating chloride processes for the treatment of these complex sulphide concentrates. Work at CANMET and under contract has largely confirmed the basic flowsheet for a ferric chloride leach process and a current contract will provide a financial feasibility study and an evaluation of its potential for use on a commercial scale.

(a) The Ferric Chloride Leach (FCL) process

The FCL process has been developed, both within CANMET and by contract research, into a technically viable process which meets the objectives of 90% metal recovery and elimination of SO_2 emission. The process appears to be economically competitive with, and perhaps superior to, conventional technology. The flowsheet which has resulted from CANMET development work is shown in Fig. 9. An economic and technical evaluation has been done under contract during the 1988/89 fiscal year to allow CANMET to fully appraise the potential of the process, and if warranted identify possible industrial partners.

A CANMET report on the FCL process has been issued providing a preliminary economic assessment.

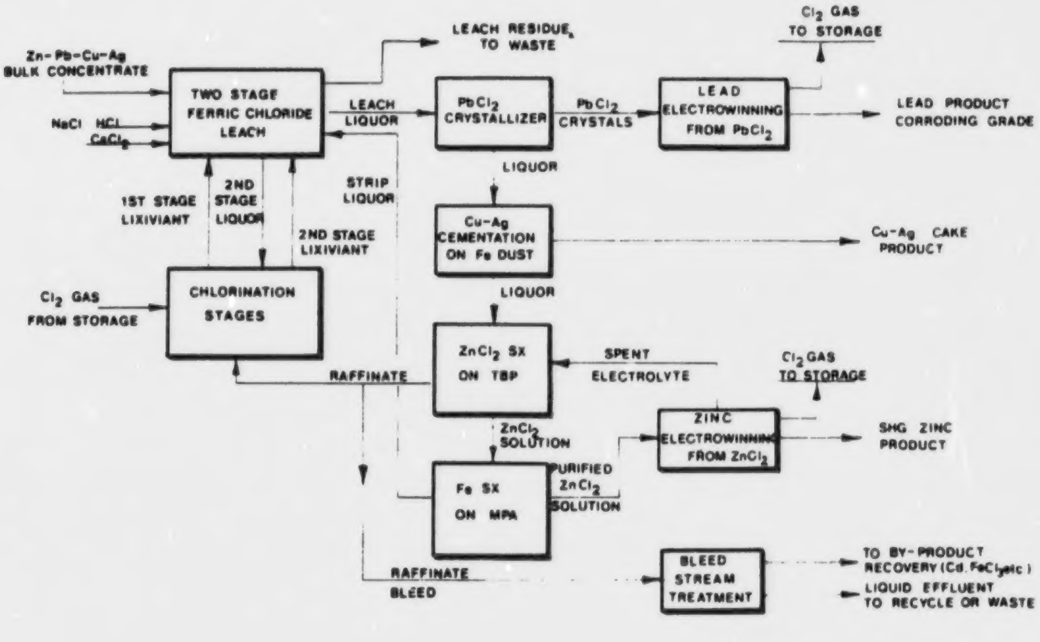

LEACH RESIDUE, TO WASTE
Cl2 GAS TO STORAGE
Zn-Pb-Cu-Ag BULK CONCENTRATE
TWO STAGE FERRIC CHLORIDE LEACH
NaCl HCl
CaCl2
LEACH LIQUOR
PbCl2 CRYSTALLIZER
PbCl2 CRYSTALS
LEAD ELECTROWINNING FROM PbCl2
LEAD PRODUCT CORRODING GRADE
LIQUOR
1ST STAGE LIXIVIANT
2ND STAGE LIQUOR
STRIP LIQUOR
2ND STAGE LIXIVIANT
Cu-Ag CEMENTATION ON Fe DUST
Cu-Ag CAKE PRODUCT
Cl2 GAS FROM STORAGE
CHLORINATION STAGES
LIQUOR
ZnCl2 SX ON TBP
SPENT ELECTROLYTE
RAFFINATE
Cl2 GAS TO STORAGE
ZINC ELECTROWINNING FROM ZnCl2
SHG ZINC PRODUCT
ZnCl2 SOLUTION
PURIFIED ZnCl2 SOLUTION
Fe SX ON MPA
RAFFINATE BLEED
BLEED STREAM TREATMENT
TO BY-PRODUCT RECOVERY (Cd. FeCl3 etc)
LIQUID EFFLUENT TO RECYCLE OR WASTE

Fig. 9. The CANMET ferric chloride leach process.

(i) Leaching - FCL process development

The two-stage $FeCl_3$ leach of a pyritic bulk concentrate has been optimized with respect to retention time and HCl concentration. At the optimum acid concentration (0.11 M HCl), and 6.0 h retention time, the optimum metal extractions were 99.6% Zn, 97.0% Ag, 99.5% Pb and 98.1% Cu.

The results are useful for plant scale-up and preliminary cost analysis. The leach liquor (pH 0.5) was chemically and physically acceptable for subsequent Cu/Ag and Zn recovery. A report has been prepared.

(ii) Sulphate control in chloride media

The deportment of sulphate during the ferric chloride leaching of a pyritic bulk concentrate was determined, and several sulphate control options were examined. Although jarosite precipitation was not effective for sulphate control at the acid concentrations required for leaching, $CaSO_4$ precipitation by the addition of either $CaCl_2$ or CaO prevented a sulphate build-up. An excess of calcium chloride is needed to control SO_4 at 1-3 g/L. Calcium sulphate contamination of the $PbCl_2$ intermediate product is a concern, but it was demonstrated that this problem could be minimized by rapid crystallization of the $PbCl_2$.

(iii) Cementation of Cu and Ag

A pH 0.5 $FeCl_3$ leach liquor was treated with scrap Fe for Cu/Ag recovery. The influence of temperature, Fe surface area, acidity and hydrodynamics were evaluated for Cu removal. Multi-stage Fe cementation was required for Cu removal to low levels (1 mg/L). Ag removal to low levels was straightforward and single stage. Two-stage Fe cementation can produce a granular product and a liquor acceptable for Zn recovery. A report has been prepared.

(iv) $PbCl_2$ recovery and purification

$FeCl_3$ leach process liquors were cooled to various final temperatures at various cooling rates to study $PbCl_2$ crystals purity and yield. Several crystal washing techniques were evaluated. The $PbCl_2$ crystal purity was much improved from previous tests and should be acceptable as fused salt electrolysis feed.

(v) Leaching of Pb/Ag residues

Several industrial process residues were tested using chloride based lixiviants. Jarosite type residues (Kidd Creek, high acid leach residue) were amenable to high chloride acidic lixiviants with 97% Pb/Ag extraction.

(vi) Solvent extraction - cadmium recovery

Work has commenced on the recovery of cadmium from the zinc solvent extraction raffinate bleed stream. It has been determined that cadmium remains in the ferric chloride circuit in the leaching loop. It is not extracted with the zinc nor is it precipitated with other products. Earlier pilot plant studies reported cadmium building to 150 ppm in solution. Selective extraction from the raffinate bleed in the presence of iron has not been achieved. However, cadmium does not precipitate with the iron removed from this stream. Preliminary tests on cadmium extraction after iron removal have shown promising results.

(b) Chloride metallurgy

(i) Leaching reactions

The leaching of galena in cupric chloride media was examined. Rapid non-linear kinetics were observed, and the leaching rate was found to increase with increasing concentrations of NaCl or HCl. The accumulation of the $PbCl_2$ and CuCl reaction products impeded the dissolution process. It was concluded that the leaching rate is controlled by the outward diffusion of the $PbCl_2$ and CuCl reaction products through the solution trapped in the pores of the constantly thickening layer of elemental sulphur, which is the dominant sulphidic reaction product.

The formation of elemental sulphur during the ferric chloride leaching of chalcopyrite was investigated. More than 95% S^0, and less than 5% SO_4, formation occurred regardless of the leaching time, the $FeCl_3$ concentration, the HCl concentration or the chalcopyrite particle size. The presence of air or O_2 actually increased the relative amount of S^0 formed. The morphology of the sulphur reaction product was determined under a wide range of experimental conditions.

(ii) Electrowinning of particulate copper

Experimental work has been completed recently on the distribution of metallic impurities (As, Sb, Bi and Pb) in particulate copper electrowon from aqueous chloride electrolyte using a specially designed electrowinning cell.

(iii) Copper cementation

The kinetics of copper cementation on rotating iron disks are being studied to determine the fundamentals of this important reaction. Different grades of iron are being examined.

(iv) Chloride processes

Testwork on lead chloride solubility, ferrous oxidation and chlorination was reviewed for final evaluation of the process. The use of chloride metallurgy for various purposes in the non-ferrous metals industry was explored.

Reports:

- Dutrizac, J.E., "The leaching of galena in cupric chloride media"; Division Report MSL 88-30 (J) Draft.
- Dutrizac, J.E., "Sulphate control in chloride leaching processes"; Division Report 88-90 (J).

- Dutrizac, J.E., "Elemental sulphur formation during the ferric chloride leaching of chalcopyrite"; Division Report MSL 88-99 (J) Draft.

- Tan, K.G., "Chlorination"; Can. J. Chem. Eng. 66(8):632-636; 1988.

- Tan, K.G., "Solubility and Systems Modelling"; Division Report MSL 88-130 (OP); 1988.

- Tan, K.G., "Co-op Report "Iron Pressure Oxidation"; May 1988.

Presentations:

- Tan, K.G., "Solubility and Systems Modelling"; 38th CSChE Conference, Edmonton; October 1988.

Extraction - Rare Metals

- **Project 30.61.02: Gold**
  Project leader : T. Cienski

Objective:

To optimize existing and to develop new methods of gold recovery from pregnant solutions.

To investigate alternate leaching processes applicable to the refractory gold ores.

To characterize the mineralogy of gold in refractory ores in order to relate physical and chemical properties to mineral processing and metal extraction.

The main focus of the CANMET Gold Project is on better understanding of the nature of refractory ores and on the improved or new technologies which will allow the mining and treatment of such ores economically. Environmental acceptability of ore treatment and extraction methods is a very important consideration in the implementation of new technology.

The research includes alternatives to roasting, cyanidation and carbon adsorption.

Appropriate seminars serve the purpose of technology transfer and of making the gold mining and processing industry aware of the research trends and of the available solutions to existing problems.

(a) Mineralogical investigations

The UP with Surface Science Western, University of Western Ontario, has been amended a second time with final delivery scheduled for March 31, 1989. The reason for both extensions was the request by Cannamex Resources Inc. to be included as a participating company. The determination of the distribution of gold, including "invisible" gold, and its implications for enhanced gold recovery has been very successful. Five reports by SSW had been completed by February 1989.

1. Direct determination of the invisible gold content of pyrite and implications on the cyanidation of the Audrey Resources tailings.
2. Determination of the mineralogical distribution of gold in a composite ore from the Howard Zone, Congress mine, B.C.
3. Direct determination of the invisible gold and complete mineralogical distribution in the massive sulphide ore from the Ketza River (Y.T.).
4. Direct determination of invisible gold in the Elmtree composite ore #1. Implications for gold recovery from oxidized and non-oxidized ores.
5. Determination of the distribution of gold in the Lara deposit, Vancouver Island, B.C.

A three-year cost recovery/cost shared joint agreement was signed and begun with Noranda Exploration Co. Ltd. on a mineralogical/analytical investigation of the occurrence of gold in refractory gold ores.

In addition to the above, three papers were prepared for publication and submitted to refereed journals. These papers discuss the newly developed methodology on the quantitative determination of the gold distribution in refractory gold ores and result from collaboration between CANMET, Surface Science Western, University of Guelph and the University of Arizona. One presentation was made at the Timmins Symposium on heap leaching in the Canadian environment (The role of mineralogy in gold metallurgy).

Contracts:

- Reqn. 7-9037, "Ion probe microanalysis of gold in common sulphide minerals and implications for enhanced recovery from refractory gold ores"; Surface Science Western. S.A. - L.J. Cabri.

(b) Thiourea leaching of gold ores and recovery from solution

Eh-pH diagrams were developed for the understanding of the gold-thiourea system. These diagrams show the influence of certain parameters, such as the concentration of thiourea, gold and formamidine disulphide. Protonated thiourea and its equivalent in the oxidized state are discussed. The diagrams are commented on in terms of the experimental results.

Reports:

- Deschênes, G. and Ritcey, G.M., "New developments in gold recovery and purification"; Division Report MSL 87-6 (OP&J).

- Deschênes, G., "Investigation on the potential techniques to recover gold from thiourea solution"; Division Report MSL 87-57 (OP&J).
- Deschênes, G., "Progrès et orientation de la recherche et du développement de l'industrie auritère"; Division Report MSL 87-131 (OP&J).
- Deschênes, G., "Techniques for recovering gold from solutions"; Division Report MSL 88-7 (OP&J).
- Deschênes, G., "Réduction par l'hydrogène: une nouvelle méthode pour récupérer l'or des solutions de thiourée"; Division Report MSL 87-78 (OP&J).
- Deschênes, G. and Ghali, E., "Leaching of gold from a chalcopyrite concentrate by thiourea"; Division Report MSL 85-124 (J).
- Deschênes, G., "Developments and applications of thiourea for processing gold deposits"; Division Report MSL 88-105 (OP&J).

Patent Application:

- Deschênes, G., "Recovery of gold from leach solution"; Can. Patent Appl. 537, 316; 1987.

(c) Gold recovery from refractory gold concentrate

Pretreatment options such as acid or alkaline leaching under oxygen pressure, microwave calcination, selective mineral decomposition and intensive preaeration have been applied on several refractory gold concentrates. Gold recoveries from these pretreated concentrates by conventional alkaline cyanide leaching process were in the range of 95-98%.

Intensive preaeration has been effective in the pretreatment of mild refractory gold concentrate, for example, flotation concentrate from Belmoral Mines Limited, Val d'Or, Quebec. It has been demonstrated that preaeration can reduce the cyanidation time to 36-48 h while providing 96-98% gold recovery. Without preaeration 100-160 h of cyanidation were needed to obtain 94-96% of gold extraction. [Division Report MSL 88-1 (CF)].

Gold recovery by CIP process requires periodical reactivation of carbon. Microwaves have been found to be effective in the reactivation of carbon. Generally, microwave reactivation of carbon requires much shorter time than thermal activation and the activation can be conducted at higher temperatures (i.e., >700 °C). Work is in progress.

(d) Recovery of gold with ion exchange and solvent extraction

The solution purification section is actively carrying out research on the use of ion exchange resins and organic solvents for the recovery of gold from cyanide solutions. Both types of extractants are believed to offer important advantages over the conventional adsorbent activated carbon. These advantages include faster kinetics and better tolerance to the presence of several organic and inorganic contaminants.

In solvent extraction, a suitable extractant has been identified that has good selectivity, high loading capacity and good physical characteristics. A pilot plant was run for a total of 115 h, during which 350 L of cyanide solution were processed. Metallic gold was recovered by distilling the diluent and burning the organic residue. Attempts to apply solvent extraction directly to pulps were less successful, due to the tendency of the extractant to become attached to the solid particles.

The present emphasis of the project has shifted to ion exchange resins, as we feel that this process is very close to finding an industrial application. We are presently in the process of patenting a novel process that uses a cationic resin to neutralize the cyanide solution and a weak-base resin to adsorb the gold. The advantage of this procedure is that gold can be readily eluted with any alkaline solution.

(e) Northern placer testing laboratory

CANMET involvement and technical support continues to assist in the Yukon placers operations gold losses study. The lack of adequate funding reduced the scope of this project, but during the summer 88 season samples were obtained from six operations. These samples were subsequently processed, gold content measured and the value of losses calculated. Conclusions and preliminary recommendations to the operators concerned are now being prepared. This project generates considerable interest within the Klondike placer mining community.

- **Project 30.61.03: Platinum Group Metals**
  Project leader : R. Molnar

Objective:

This project was created to develop at a laboratory scale a process for the recovery of platinum group and associated metals from Canadian sources in collaboration with industry. Work in this project depends on demand from cost recovery clients and resources are allocated based on such demands.

As there was no specific cost recovery inquiries in this area in the past year, no laboratory work has been carried out. Negotiations have been underway for some time regarding the licensing of the platinum palladium extraction flowsheet develop at CANMET by a Canadian company which has also carried out a detailed pilot scale evaluation of this technology. The technology was also considered by another company as part of a process to recover platinum from spent automobile exhaust catalyst, but will not be used because of lead co-extraction problems identified in this work. CANMET scientists have actively been consulted on both of these investigations.

In a related vein a literature survey on platinum group metals mineralogy and extraction technology was carried out and reported (see Minerals Evaluation).

- **Project 30.61.05: Oxide Ores**
  Project leader : R. Molnar

Objective:

MSL has received numerous inquiries from the field on processing problems encountered with a number of different oxide ores. The inquiries have related to both the recovery of metals from new prospects and the recovery of new by-products from existing operations. In order to be able to internally support some of the required cost recovery research and to be able to investigate and develop novel technologies relevant to the problems being presented, this project was initiated. Specific research targets were to be determined by the nature of the industrial inquiries being received.

(a) Ion exchange recovery of gallium

Further work has been carried out on the use of an amidoxime resin to recover gallium from Bayer Process solutions. Loading and elution recycling tests (20 cycles) have demonstrated the technical viability of the approach. Techniques for controlling the vanadium poisoning of the resin have been identified.

There can be a gradual degradation in the capacity of the resin observed in acid media. Used resins were examined by Fourier transform infrared spectroscopy. Differences between fresh resins and those from recycling tests stripped with various acids were not readily interpreted when the resins were examined in their acid salt form. After sodium hydroxide treatment, the spectra of the recycled and the acid stripped resins indicated that the oxime group had been depleted. Amidoximes can hydrolyse to hydroxamic acids in weak acid solution. These spectra also showed evidence of an increase in ionized hydroxamate groups, evidence which was absent in spectra of resin treated with strong acids (which would suppress dissociation of the hydroxamic acid).

Acid is required for stripping but degradation can be controlled by selection of the type and concentration of the acid. Stripping with complexing agents is also technically viable but the recycling of the reagents has not been proved out and this may make their use uneconomical.

Reports:

- Riveros, P., "Ion exchange recovery of gallium from Bayer liquors"; Division Report MSL 89-26 (J).

(b) Uranium

No laboratory work was undertaken on uranium this year. However, two papers were presented and published from previous years' data. The first dealt with leaching of the high grade Midwest Lake complex uranium ore in chloride medium to give high extractions of U, Ni, As and 226-Radium and so yield a clean tailings. The second examined the leaching of radium with various agents from contaminated soil from Scarborough County. Chloride was the most effective.

Standards and Specifications

- **Project 30.69.01: Reference Materials**
  Project leader : C.W. Smith

Background:

In Canada, CANMET has accepted a lead role for the production and certification of mineralogical and metallurgical CRMs through the Canadian Certified Reference Materials Project (CCRMP). The progress and focus of CCRMP is reviewed annually by an Advisory Committee comprising representatives of the industrial, commercial and institutional laboratory sectors of Canada. Measurements for the certifications of CCRMP are contributed by laboratories in Canada and throughout the world. CANMET also contributes to and keeps appraised of the international focus of reference materials by participation in the Canadian Advisory Committee on REMCO (Committee on Reference Materials of the International Standards Organization).

Objective:

To support the reliability and quality of chemical and physical measurements of mineralogical and metallurgical materials of Canadian need and interest by the preparation and certification of minerals, ores, concentrates, metals, tailings and related materials for use as reference materials for composition.

Demand for Reference Materials:

The demand for CCRMP CRMs continued to grow in 1988. Some 2000 units were distributed producing a revenue of some $166,000 - a 14% increase over 1987 and 52% over 1985. CCRMP materials are internationally recognized; 64% of distribution was external to Canada. Gold ore CRMs continue to lead demand.

Marketing Endeavors:

An exhibition display was created and shown first at the Canadian Mineral Analysts Conference held in Rouyn/Noranda, Quebec. CCRMP was also featured at CANMET displays at seminars in Val d'Or, Quebec and Timmins, Ontario. A Fact Sheet on CCRMP was created for CANMET promotional packages and CCRMP direct mailings.

New CRMs made Available in FY 1988

- Zinc-Aluminum (ZA) Alloys: Seven ZA foundry alloy RMs, produced in cooperation with Noranda Inc. were made available in December.
- Uranium Ore Concentrate (CUP-2): Produced in cooperation with the Canadian Uranium Producer's Metallurgical Committee (CUPMC/AC), Eldorado Nuclear and CANMET, recommended values are provided for uranium and 16 other constituents.
- Thorium/Rare Earth Ore (OKA-2): Certified for uranium and thorium in an IAEA/CCRMP cooperative measurement program. OKA-2 was made available in December. Measurement efforts continue towards certification of several lanthanide elements, which as oxides comprise more than 30% of the matrix.
- Compressive Strength Monitor Cement (CM-1): A CSA Type 20 cement, CM-1 was produced by the CSA Committee on Hydraulic Cements with the cooperation of MSL/CANMET and made available through CCRMP in December.
- Sulphide Ore Tailings (RTS-1 to 4): Produced in cooperation with the industry/CANMET "MEND" program, the RTS series provide reference materials of pyritic and pyrrhotitic tailings of various stages of oxidation. The materials will be available for the 1989 field measurement program of MEND.

Current Objectives:

- Gold Ore (MA-1b): Replacement material for MA-1a was obtained with the cooperation of Lac Minerals Limited and a certification program initiated in March 1989.
- Exploration/Geochemical CRMs for Gold and Platinum Group Elements (UMT-1, TDB-1, WGB-1, WPR-1, WMG-1, WMS-1): Six rock matrix materials with varying amounts of Au and PGE mineralization were obtained with the cooperation of Westcoast Minerals, Mascot Gold, Cathro Archer and the GSC. These are in preparation as candidate CRMs for 1989 measurement programs.

Future Direction:

- Replacement of Gold Ore MA-2a (2 yr): Samples for testing have been obtained with the cooperation of Placer Dome Inc.
- Replacement of Platiniferous Nickel/Copper Concentrate PTC-1 (1.8 yr): Material WMS-1 will be tested for suitability. Initial contact with INCO has been made with respect to replacement material.
- Cost Recovery Preparations: Requests are anticipated.
- Copper Anodes and Anode Slimes: An industry/CANMET round robin on the measurement of constituents indicates a need for reference materials. A potential market of 200 refineries exists. Several samples are being obtained for feasibility studies.

Reports:

- Smith, C.W., Steger, H.F., Kerbyson, J.D. and Bowman, W.S., "Zinc-aluminum foundry alloys NZA-1 to NZA-7: Reference materials for chemical composition"; Division Report MSL 89-7 (R).

- Dalton, J.L. and Bowman, W.S., "CUP-2: A Certified Uranium Ore Concentrate"; Report CCRMP 88-3.

Contracts:

- Reqn. 8-9062, "Collection of precious metals-bearing rock sample for the preparation of CCRMP reference material"; Westcoast Minerals. S.A. - C.W. Smith.

CCRMP / PCMR
CANMET
FROM THE GROUND UP

Fig. 10. CCRMP display booth at the 20th Canadian Mineral Analysts Conference, held in September in Rouyn-Noranda, Quebec.

- **Project 30.69.02: Analytical Methodology**
  Project Leader: J.C. Hole

Objective:

To develop and improve analytical methods, techniques, and laboratory facilities, mainly in support of CANMET programs, and to participate in working groups and/or serve on committees of national and international organizations which develop and disseminate information on standard analytical methods.

The development of new analytical methods and techniques and the refinement of the existing methodology are essential to meet the increasing needs for faster and more accurate analytical results. The application of techniques such as infrared analysis, differential thermal analysis, thermogravimetric analysis, X-ray powder diffraction, X-ray fluorescence, inductively coupled plasma emission spectroscopy, atomic-absorption spectrophotometry and ion chromatography extend the analytical capability of the laboratories and contribute to the success of the CANMET research activities.

The International Organization for Standardization (ISO) is responsible for the establishment of international standards for a wide range of materials and products. The application of these standards facilitates orderly trade in the commodities and hence is beneficial to Canada as a large exporter. These standards can also have a significant effect on the acceptability of Canadian mineral and metallurgical products in international markets. CANMET, therefore, is taking an active role in several ISO committees and participates in other standards committees such as ASTM, etc. A number of Canadian companies actively share in this work.

(a) Industrial support and analytical research

At the request of the ASTM Task Force on Silica Fume (Task Group 4, C09.03.10), a CANMET gravimetric method for the determination of silica was evaluated and proposed for application to silica fume.

A proposed fusion-atomic absorption method for the determination of calcium and magnesium in aluminum ores was evaluated for Alcan International Limited.

Flow-injection methods for the analysis of gold mill effluents have been developed. Total cyanide, dissociable cyanide, and thiocyanate may all be determined by variations of this technique, which will allow for a much faster analytical turnaround than conventional methods.

A flame atomic absorption method involving solvent extraction has been developed for the determination of microgram levels of cobalt, nickel, lead, bismuth and indium in ores, soils and sediments.

A graphite furnace-atomic absorption method has been developed for the determination of microgram levels of tellurium in ores, concentrates, rocks and sediments.

Developments in high-performance liquid chromatography have enabled the determination of rare-earth elements in rocks, lake sediments and alloys, and also have reduced the detection limit to 0.5 ng of rare-earth elements.

An analytical scheme has been developed for the determination of free thiourea, complexed thiourea, and formamidine in gold-thiourea leach solutions.

A hydride-generation atomic absorption method has been developed for the determination of small amounts of tellurium in precious metals leach solutions.

(b) Standards development

MSL has continued to make substantial contributions to the on-going work of the International Organization for Standardization (ISO) in conjunction with the Standards Council of Canada, by participation in collaborative laboratory testing and evaluation of analytical methods. MSL officers are chairmen and convenors of a number of ISO technical committees and working groups, and collaborate with twelve Canadian industries in this work.

Close involvement continues with the work of ISO/TC 102 (Iron Ores), ISO/TC 183 (Copper, Lead and Zinc Ores and Concentrates), and ISO/TC 69 (Application of Statistical Methods). Two interlaboratory studies of proposed international standards methods were completed, and numerous studies were conducted for the statistical evaluation of proposed methods. MSL continues to serve as the international centre for the storage and critical evaluation of all data generated by these two technical committees.

MSL officers assisted with the organization of the international meeting of ISO/TC 183 in Ottawa in May 1988. Others attended the international meeting of ISO/TC 102 in Belo Horizonte, Brazil, in October 1988.

Future Direction:

Work will continue on enhancing the analytical capabilities of the Chemical Laboratory. Emphasis will be placed on ion chromatographic techniques for determination of anions in mineral processing residues and solutions, and the determination of low levels of elements of environmental concern in ores and processing products.

The commitment to the work of international standards organizations is on-going. Efforts will continue towards the establishment of international standard methods for iron ore, and for copper, lead and zinc ore analysis. The international data storage facilities will be maintained.

Reports:

- Barkley, D.J., "Dynamic ion-exchange chromatography for the determination of rare earths in samples from metallurgical processes"; Division Report MSL 88-116 (OP).

- Dalton, J.L., "Workshop presentation (1) Overview of radioactive materials available from the Certified Reference Materials Project (2) Radiochemical measurements on nickel sulphide concentrate"; Division Report MSL 88-46 (OP).

- Donaldson, E.M., "Determination of cobalt, nickel, lead, bismuth and indium in ores, soils and related materials by atomic-absorption spectrometry after separation by xanthate extraction"; Division Report MSL 88-111 (J) (in press).

- Moloughney, P.E., "Determination of precious metals in bauxite and red muds from Alcan International Ltd."; Division Report MSL 88-10 (CR).

- Steger, H.F., "Workshop presentation - Quality control is like knowledge - A little bit can be dangerous"; Division Report MSL 88-40 (OP).

- Sweileh, J.A., 'Determination of cyanide and thiocyanate by a flow-injection-spectrophotometric method"; Division Report MSL 88-114 (J).

- Sutarno, R. and Dalton, J.L., "Use of statistical technique in chemical analysis and process control"; Division Report MSL 88-10 (TR).

- Sutarno, R. and Bowman, W.S., "ISO/TC 183/WG 1B - Determination of gold and silver in copper concentrates by fire assay method - Statistical evaluation of international test data 1986-1988"; Division Report MSL 88-24 (OP&J); ISO/TC 183 N 226E.

- Sutarno, R. and Bowman, W.S., "ISO/TC 183/WG 2A - Determination of gold and silver in copper concentrates by fire assay - AAS/titrimetric method - Statistical evaluation of international test data 1986-1988"; Division Report MSL 88-26 (OP&J); ISO/TC 183 N 237E.

- Sutarno, R. and Bowman, W.S., "ISO/TC 183/WG 3B - Determination of copper in copper concentrates by titrimetric method - Statistical evaluation of international test data 1986-1988"; Division Report MSL 88-27 (OP&J); ISO/TC 183 N 245E.

- Sutarno, R. and Bowman, W.S., "ISO/TC 183/WG 4B - Determination of copper in copper concentrates by electrogravimetric method - Statistical evaluation of international test data 1986-1988"; Division Report MSL 88-28 (OP&J); ISO/TC 183 N 215E.

- Sutarno, R. and Bowman, W.S., "ISO/TC 183/WG 5B - Determination of lead in lead concentrates by titrimetric method - Statistical evaluation of international test data 1986-1988"; Division Report MSL 88-33 (OP&J); ISO/TC 183 N 220E.

- Sutarno, R. and Bowman, W.S., "ISO/TC 183/WG 8A - Determination of gold and silver in zinc concentrates - Statistical evaluation of international test data 1986-1988"; Division Report MSL 88-42 (OP&J); ISO/TC 183 N 230E.

- Sutarno, R. and Bowman, W.S., "ISO/TC 183 - Precision of ISO draft methods for the determination of Au, Ag and Cu in copper concentrates"; Division Report MSL 88-91 (OP).
- Sutarno, R. and Bowman, W.S., "ISO/TC 102/SC 2/WG 24B - Direct reduced iron - Determination of carbon sulphur - High frequency/infrared measurement - Statistical analysis of international test data 1986-1988"; Division Report MSL 88-92 (OP&J); ISO/TC 102/SC 2 N 929E.
- Sutarno, R., "ISO/TC 102/SC 2 - 14th International meeting, Belo Horizonte, Brazil, 1988-10-23/28"; Division Report MSL 88-138 (TR).

Environmental Controls

- **Project 30.86.01: Tailings Characterization and Control Mechanisms**
  Project leader : M.P. Filion

Background:

Solid wastes from Canadian mining operations frequently contain sulphide mineralization, which produce acid mine drainage when exposed to air and water. Acid drainage carries toxic heavy metals into the environment, and the combined effect can cause severe long-term ecological damage. Acid mine drainage can be effectively treated; however, the operation and maintenance of chemical treatment plants, for hundreds of years, is unacceptable and impractical. Preventative technologies are required if industry is to remain competitive.

In response to the acid mine drainage problem, a tripartite research proposal has been prepared, and involves industry, CANMET, Environment Canada, British Columbia, Manitoba, Ontario, Quebec and New Brunswick. The program will be known as the Mine Environment Neutral Drainage (MEND) Program. Implementation of the research proposal will require an expenditure of $12.5 to $15 million over a five year period. Industry has committed one third of the project costs, subject to the two levels of government matching these funds.

Benefits:

Briefly, the project will provide the following benefits:

- development of new AMD prevention and control technology;
- reduced mine site closure costs;
- improved international competitiveness;
- new opportunities for Canadian consulting firms;
- an improved understanding of environmental processes; and
- environmental protection.

Objectives:

MEND research programs will be selected with the following objectives in mind:

- to provide a comprehensive, scientific, technical and economic basis for the mining industry and government agencies to predict with confidence the long-term management requirements for reactive tailings and waste rock; and
- to establish techniques that will enable the operation and closure of acid generating tailings and waste rock disposal areas in a predictable, affordable timely and environmentally acceptable manner.

In support of the objectives of this project experimental work has been carried out at CANMET to develop methodology for the effective control and disposal of potential environmental contaminants discharged from mine/mill operations.

CANMET sees its contribution as directed towards a number of goals, namely:

- contribution to the development of new processing steps for the removal of pollutants in mills prior to discharge;
- development of methods for the treatment of effluents; and
- development of methods for containment technology.

Achievements:

This program was originally known as the Reactive Acid Tailings (RATS) program. The program name was changed to MEND in 1988/89 to raise the profile of the program in preparation for project initiation during the fiscal year. A Board of Directors was established, and consists of senior vice-presidents from the mining industry, and assistant deputy ministers from the two levels of government. A Management Committee and six Technical Committees were established to direct the day to day research activities of the program.

Eleven projects were underway or completed during the fiscal year 1988/89, for a total budget of $1,665,000. Total expenditures in 1988/89 amounted to $487,000. The projects cover a period of one to five years, and were initiated using existing government and industry resources. New funds have not been allocated by any of the participating governments, although efforts in this area continue. New funds will be needed if the program is to meet its objectives in a time frame of five to seven years. Industry will contribute one-third of the program costs, but these funds must be matched by the federal government and the provinces.

(a) Lysimeter studies

Lysimeters continued to be the major test procedure in the examination of tailings. They have been employed in a number of different disposal simulation tests.

(i) Bog covers over different types of tailings indicate an effective control method where natural conditions are suitable.

(ii) Bog cover over an Elliot Lake uranium tailing has shown that the type of plant material influences the results.

(iii) Simulated deep lake disposal tests of thirty simulated years with a high pyrite sample remained acidic while the pH over a uranium tailing has stayed neutral. The acidity of the pyrite test is partly ascribed to the use of pre-oxidized tailings and demonstrates the long-term acid producing potential of such materials even under relatively oxygen-poor conditions.

(iv) AMD predictive techniques comparing 11 methods with 13 samples of tailings and waste rocks show that the most reliable techniques are the humidity cells and the lysimeter tests. The report will be available shortly.

(v) Leaching of New Brunswick manganese ore using acid generated from sulphidic tailings shows Mn buildup to the 10 g/L range. This could be a source of manganese.

(vi) Samples of tailings have been under test for underwater disposal.

(vii) A textbook entitled, "Tailings Management" was completed and forwarded to the publisher Elsevier with publication scheduled for May 1989.

(viii) There have been numerous contact with CANMET for advice and assistance regarding the design and operation of tailings disposal facilities and related topics.

Publications:

- "Research Plan - Reactive Acid Tailings Stabilization Program (RATS)"; SP88-3.

- **Project 30.86.03: Water Pollution Control**
  Project leader : R.J.C. MacDonald

Objective:

To establish technology for the control of water pollution to meet the standards set by regulatory agencies for the mining and processing of minerals. This will be accomplished by identifying potential problems and examining methods for the removal of environmental contaminants from mining or metallurgical processes liquid waste streams.

The current high level of activity in gold is giving rise to concern for waste cyanide recovery or destruction for both economic and environmental reasons. As well the numerous effluent treatment facilities recently being used by the Canadian industry generate large volumes of waste sludges. Environmentally acceptable methods for disposal of these sludges may be inadequate and already disposed sludges may require further treatment.

The ever increasing awareness and concern for protection of the environment makes it essential that economical and environmentally sound technologies be developed if the Canadian mineral industry is to remain viable.

(a) Arsenic precipitation from hydrometallurgical processing solutions

The precipitation of Co-Ni-Mg arsenates using a slow addition method is being examined. Although rapid mixing of the solutions results in amorphous phases, with high arsenic solubilities, slow-addition produces well crystallized solid solution members. The arsenate species precipitated depends on the concentrations of both the metal and arsenate ions. Complete solid solution seems to exist in the Co-Ni-Mg arsenate ternary field.

The behaviour of arsenic during the hydrothermal conversion of jarosite to hematite has also been studied. Although 90% of the arsenic present in the jarosite remains with the hematite, some undesirable arsenic dissolution occurs. The form of arsenic in the hematite is unknown.

(b) Analytical development

(i) High-performance liquid chromatographic determination of anionic species in the AVR cyanide recovery process

The development of an HPLC system involving a reverse phase coated with cetyltrimethyl-ammonium ion to determine anionic species was reported in last annual report. However, a drawback to this system is the occurrence of one or more induced peaks, due to the disturbance of the adsorption equilibrium, and this can interfere with solute peaks. By optimizing both eluant and sample pH with a cationic buffer, system peak interference was reduced to permit more accurate and reproducible results.

(c) Cyanide and metal recovery from gold mill barren solutions

A contract for feasibility testing of CANMET's acidification, volatilization, reneutralization (AVR) technology utilizing plant barren solution (Merrill-Crowe), was negotiated with a major gold producing client. This investigation lead to development of a revised, and novel, cyanide recovery feature. The improvement to the process resulted in a significant reduction in both the capital cost and the projected operating costs of the AVR concept. A substantial capital payback for the process over a 3-5 year period dependent upon cost of cyanide reagent delivered at site can be predicted. No alternative process for control of metallocyanides in gold mill effluents can provide for an ultimate return on investment based solely on cyanide recovered for reuse. In addition, AVR procedures produce an environmentally acceptable waste water.

Contact with a Quebec Merrill-Crowe gold mill operation has resulted in an opportunity to do a preliminary evaluation of a considerably different barren solution for cyanide recovery potential. The prospects for implementation of a comprehensive feasibility study are promising.

During the year, increased awareness of the potential of AVR technology by the gold industry has escalated appreciably through presentations at seminars in various part os the country.

It appears probable that the prospect of a substantial cyanide recovery from Merrill-Crowe type barren solutions (filtrates) will demand a greater appreciation of the Merrill-Crowe process for many Canadian operations. The prospects are equally good for effective processing of heap leach barren recycle and barren bleed.

Additional incentives for seriously considering this cyanide recovery process are:

- avoidance of the very substantial reagent costs associated with cyanide destruction by chemical oxidation;
- no metallocyanide solids are deposited into the mill pond;
- no CNO^- is introduced into the effluent;
- minimized content of base metal hydroxides are discarded into mill pond with the process effluent; and
- reliability, unsophisticated control (pH).

Economic comparison of Merrill-Crowe vs C.I.P. technology should include the increasingly important effluent control factor and concomitant cyanide recycle.

(d) Radium adsorption

Lysimeter effluent is currently still being fed to the contactor containing fluidized, finely-ground barite. The total throughput is now six tonnes averaging 100 pCi Ra^{226} per litre. The output remains at 10 pCi/L and therefore the estimated radium loading on the barite is 10,500 pCi/g. The residence time in the mechanically stirred unit remains at 5½ h.

CANMET's lysimeter studies have been terminated. The supply of feed solution to the reactor is almost exhausted. Therefore, this testwork will be terminated and the barite content of the reactor examined and analyzed for radium concentration.

Future Direction:

Work on precipitation of arsenic will continue. Demonstrations and promotion of the economic as well as environmental aspects of CANMET's AVR technology for cyanide will be continued. In analytical development the application of flow injection analysis (FIA) to the determination of cyanide will be investigated. Methods for the determination of individual thiosalts will also be developed.

Contracts:

- Reqn. 7-9212, "Minimization/utilization of mill effluent sludges"; Gionet, Mellor and Liebich Associates Ltd. S.A. - R.J.C. MacDonald (Final report).

- "Application of AVR process for cyanide recovery and cyanogen control for barren recycle and barren bleed"; Placer Dome Contract; Division Report MSL 88-18 (CR). S.A. - V.M. McNamara.

Reports:

- McNamara, V.M., "The AVR process for cyanide recovery and cyanogen control for barren recycle and barren bleed"; Division Report MSL 89-13 (OP&J).

- McNamara, V.M. and Ritcey, G.M., "Cyanide abatement processes for gold mill effluent treatment"; Division Report MSL 88-3 (OP&J).

- Haque, K.E. and Griffith, W., "Gold ore leaching with barren recycle cyanide solution"; Division Report MSL 89-5 (TR).

Fig. 11. CANMET's pilot-scale AVR process for cyanide recovery.

- **Project 30.86.04: Air Pollution Control**
  Project leader : J.M. Skeaff

Objective:

The objective of this project is to evaluate and where feasible to develop effective and acceptable methods for the monitoring and control of noxious elements encountered in Canadian pyrometallurgical processes. Investigations will focus on developing thermal data presently lacking for arsenides and arsenates, as well as methods for eliminating SO_2 in smelter off-gases.

The emissions of noxious elements and their compounds during pyrometallurgical processing of Canadian ores and concentrates is an area of concern to federal and provincial health and environmental protection organizations as well as to private industry. Of particular concern are non-ferrous roasting and smelter operations which result in SO_2 emissions as well as the emission of arsenic and mercury, and in many cases small quantities of other toxic elements such as cadmium, selenium, tellurium and lead. A need exists for more definitive data on the disposition of these trace elements in concentrates and process streams, and on modifying flowsheets or developing pollution abatement equipment for the economic removal and disposal or recovery of these elements. In particular those associated with dusts from smelters which, due to economic or location factors, do not have an acid plant and thus constitute particular problems as do the roasting operations associated with the recovery of gold, silver, nickel and cobalt from arsenical ores.

(a) Thermochemical studies of arsenides and arsenates

An investigation of the thermochemical properties of certain arsenates and arsenides is being conducted by an equilibrium electrochemical technique in which a partially stabilized ZrO_2-CaO electrolyte is employed in an oxygen concentration cell to measure galvanic potentials. To date, thermochemical studies for the nickel arsenides and $FeAsO_4$ have been completed and preliminary data for $Pb_3As_2O_8$ have been obtained.

A study of the oxidation and thermal dissociation of skutterudite [$(Co,Fe,Ni)As_3$] by differential thermal (DT) analysis and thermogravimetry has been completed. The oxidation of skutterudite was found to be a complex process which indicated the simultaneous dissociation to lower arsenides and arsenic, and the oxidation of the products of arsenates and arsenic oxide vapour.

A thermogravimetric (TG) analysis study has also been completed to determine the behaviour of synthetic skutterudite [$CoAs_3$] and safflorite [$CoAs_2$] when heated in inert atmospheres. The results indicate that both compounds dissociate to lower arsenides and elemental arsenic vapour under non-oxidizing conditions above $\sim 500\,^{\circ}C$ and $\sim 600\,^{\circ}C$ respectively.

The data resulting from these studies can be used to predict stable condensed phases and gas compositions occurring under roasting or other pyrometallurgical conditions. Increasingly, industrial support is being expressed for this project.

Future Direction:

Work will continue on the characterization of the thermochemical properties of the arsenates of Pb, Ni and Co. TG and DT studies will continue on the behaviour of arsenopyrite under oxidizing and inert conditions.

Publications:

- Skeaff, J.M., "Thermochemical arsenate-oxide equilibria in the system Fe-As-O determined electrochemically between 317°C and 536°C"; accepted for publication, Canadian Metallurgical Quarterly; 1989.
- Mikhail, S.A., Turcotte, A.M. and Bowman, W.S., "A study of the decomposition of higher cobalt arsenides by thermal analysis"; Proceedings of the 17th North American Thermal Analysis Society Conference, ed. C.M. Earnest; 46-52; 1988.
- Wilson, L.J. and Mikhail, S.A., "Investigation of the oxidation of skutterudite by thermal analysis"; Proceedings of the 17th North American Thermal Analysis Society Conference, vol. 1, ed. C.M. Earnest, 53-59; 1988.

Contracts:

- Reqn. 6-9066, "Development of a solid state sulphur probe for use in pyrometallurgical processes (UP-M584)"; J. Kirchnerova and C.W. Bale, Ecole Polytechnique, Montreal. S.A. - J.M. Skeaff.

Patent Application:

- Kirchnerova, J., Skeaff, J.M. and Bale, C.W., "A solid state arsenic probe for use in pyrometallurgical processes"; United States Patent Appl. No. 052,027.

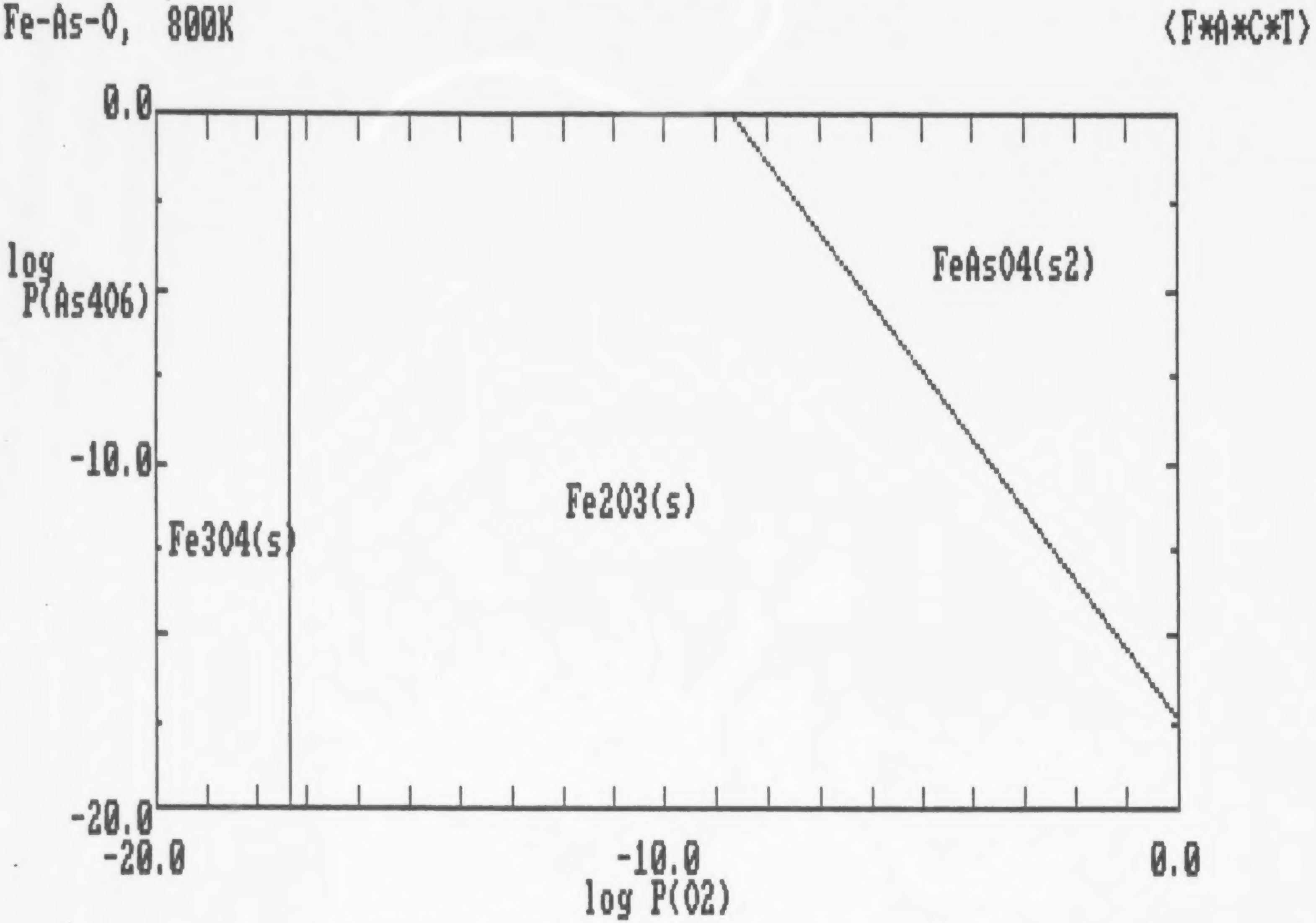


Fig. 12. Predominance area diagram of Fe-As-O at 800K (527 °C).

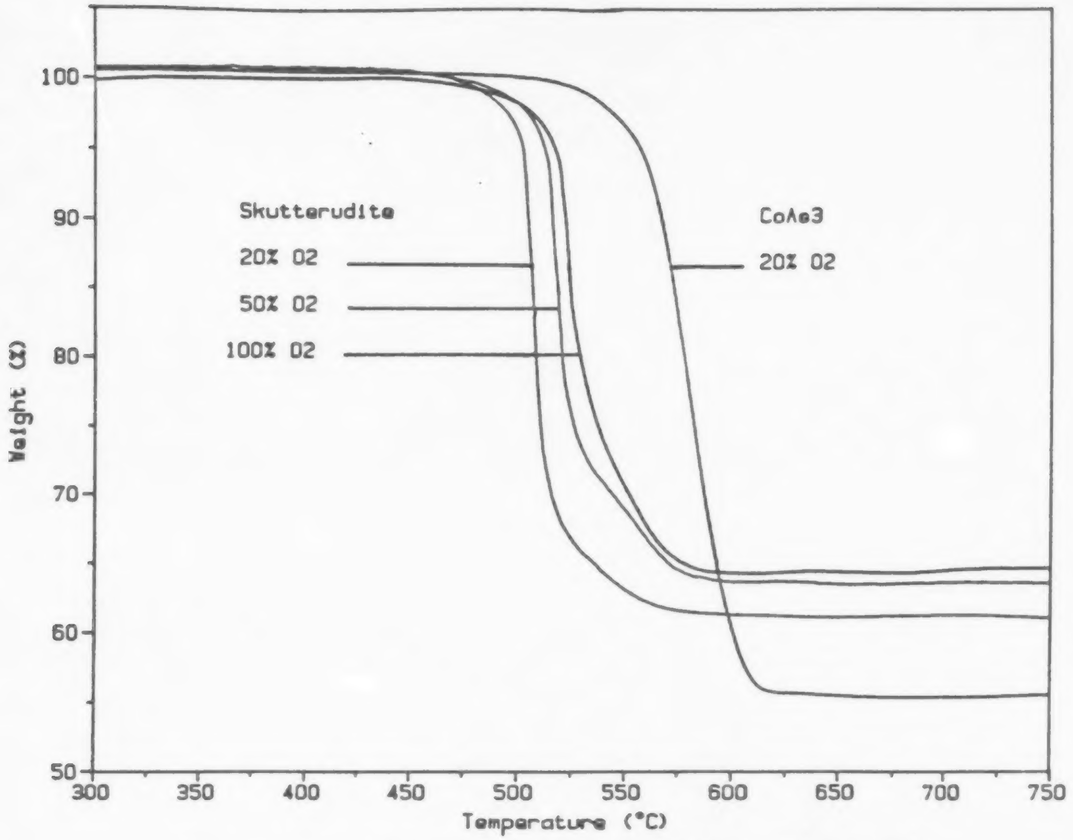


Fig. 13. TG diagrams for skutterudite (<38 μm) and synthetic $CoAs_3$ in different oxygen partial pressures.

Fluidized-Bed Combustion

- **Project 50.62.06: Fluidized Bed Combustion Systems**
  Project leader : F.D. Friedrich (ERL)

Objective:

To investigate the SO_2 emission and its capture by sorbents (limestone) in bench and pilot scale fluid bed systems and to develop a technique for predicting limestone performance in CFB environment.

Fluidized bed combustion technology is proving itself capable of utilizing high sulphur coals, while meeting environmentally standards, for the generation of electricity and process steam. Two major demonstration combustors are in operation at Summerside, P.E.I. and Chatham, N.B. and a 150 MW unit is planned for Nova Scotia. The work on this project in MSL has evaluated SO_2

sorbents for all these units and is helping to understand the behaviour and utilization of limestones in fluid bed combustion.

(a) Characterization of the sulphur sorbent performance of Canadian limestones

A thermogravimetric analyzer (TGA) was built to study calcination and sulphation reactions of limestones. This TGA utilizes samples weighing 1-2 g dispersed within a quartz wool matrix in an open quartz basket. This technique permits the study of a wide particle size range. It is more representative than other TG methods which use 50-100 mg of sample in a shallow pan. The bench-scale fluidized bed reactor (FBR), which was developed and used to evaluate limestones for bubbling bed fluid beds, cannot be used to test the finer sized limestone encountered in CFBCs because of elutriation on sample from the unit. The new TGA does not have this problem and can be used to evaluate fine sized sorbents.

Five Nova Scotia limestones, which were tested in the Chatham CFBC, were also evaluated by the FBR and TG methods. Although the TG gave higher sulphation capacities than the FBR, presumably due to the loss of sample from the FBR by attrition, the ranking of the limestones was similar to that found in the Chatham tests.

The work on modelling SO_2 capture in a CFBC is closely related to the TG work. The proposed model requires that a global reaction rate be determined empirically for each limestone type. This rate expression can be determined using the TG data. The two limestones tested, Havelock and Fort McMurray, behave according to theoretical expectations, which indicates that the reaction sub-model can be incorporated into the overall circulating fluidized bed model as proposed.

(b) Characterization of reaction products from fluidized bed combustion

The thermogravimetric method which had been developed to analyze the major components of fluidized bed ash, was further improved to include the determination of iron oxide in the ash. This was achieved by changing the heating profile during the reduction stage of the TG method. Thus, the modified method gives quantitative determinations for: H_2O, $Ca(OH)_2$, C, $CaSO_4$, $CaCO_3$ and Fe_2O_3. In a round-robin analysis of five synthetic ash samples by five laboratories, the TG method was found to be accurate, reproducible and convenient.

A series of ash samples from two test runs at the Chatham CFBC were examined by scanning electron microscopy. The samples were taken from the fluid bed, heat exchanger, ash cooler, back pass and baghouse. It was found that the coarser sized lime particles which remain in the combustor was more effectively utilized than the finer lime particles. Poor cyclone efficiency allowed the finer particles to leave the system without recycle.

(c) Circulating fluidized combustion

MSL's 100 mm diam CFBC was extended an additional 2 m to 5 m to provide additional gas residence time for better sulphur capture. The added surface area for heat loss resulted in a longer start up time (4 h), however, the overall heat balance and temperature profile changed little from the previous configuration. A secondary cyclone added to the system has proven effective in reducing excessive elutriation loss when fine materials are tested.

Reports:

- Hamer, C.A., "Evaluation of SO_2 sorbent utilization in fluidized beds"; CANMET Report 86-9E.

- Liang, D.T. and Hamer, C.A., "Sulphur capture during the combustion of Minto coal in a 100-mm diam CFB combustor"; Division Report MSL 88-41 (OP&J).

- Anthony, E.J., Liang, D.T. and Hamer, C.A., "Sulphur capture and its sulphur forms in fluidized bed combustion"; 38th Canadian Chemical Engineering Conf., Edmonton; 1988.

- Hamer, C.A. and Owens, D.R., "Scanning electron microscopic examination of Chatham circulating fluidized bed combustion ashes"; Division Report MSL 88-81 (TR).

MINERAL DEVELOPMENT AGREEMENTS

Manitoba

Under the Research and Technology Sector of the Canada/Manitoba Mineral Development Agreement, CANMET's Mineral Sciences Laboratories are responsible for delivery of the federally funded Processing Technology projects. During FY 1988/89 there were eight active federally funded processing projects with forecast expenditures of $796.5K.

An updated report incorporating the latest cost estimates for copper smelter modernization at Hudson Bay Mining and Smelting has been published (CANMET MSL 88-29). The GCM process, although potentially the best long-term alternative for SO_2 control at the Flin Flon copper smelter will not be further developed to verify techno-economic viability unless SO_2 regulations force re-evaluation of the situation.

Under the project on the recovery of gold and silver from Zinc Pressure Leach (ZPL) sulphidic residues, a comparative economic evaluation indicated that either cyanidation or a CANMET pyrometallurgical process was attractive. Although the capital costs are higher the pyrometallurgical process is simpler, has higher recoveries, lower operating costs and no potential environmental problems related to cyanide disposal.

A process has also been developed under contract for recovery of the gold and silver from the oxide fraction of the ZPL residues. The proposed process is technically and economically viable with an estimated capital write-off period of three years.

A project on pyrrhotite rejection is progressing on schedule and has shown that emphasis on resolving the smelter energy balance is required.

Work on the HBMS circuit report is continuing. Significant losses of both Cu and Zn to the tailings in the unrecoverable form of solid solution in slag fayalite, and as recoverable (and/or regrindable) chalcopyrite and sphalerite, respectively are indicated. Principal losses of Zn to the Cu-concentrate are as recoverable free and sub-free sphalerite grains. Covellite and chalcocite derived from alteration of Cu-matte entrained in the backfilled slag are significant potential activators of the sphalerite.

Presently, samples are being collected from both the Namu Lake and Callinan ore deposits, and samples of the principal end products from the two Snow Lake concentrator circuits.

Work is continuing under contract for the recovery of metal values from tailings residues at HBMS. Phase III has recently been initiated.

The two shared-cost contracts at Ruttan Mine on column flotation and flotation process control are behind schedule mainly due to inability to obtain capable personnel. Recent indications are that efforts to complete the projects will be undertaken in the near future.

A contract on D-cracking of concrete were awarded in July 1988 and has been completed. Basically, this work involved the examination of roads within the province for damage caused by the swelling of aggregates (D-cracking).

Work on the Bird River chromite continued under contract. The four major process areas that impact both capital and operating costs for hot band production were reviewed. Nickel sources were investigated in order to identify lower priced materials. The smelting process was investigated to determine the potential cost savings when employing new technologies. Steelmaking operations were redefined as a result of the smelting process review and the market survey. The slab casting and hot rolling operation was developed to identify the most cost-effective practical alternative system for hot band production.

By the end of November 1988, studies has been completed on the marketability of stainless slab and hot band, opportunities in the chrome chemicals industry, the applicability of new smelting, steelmaking and casting technologies and an overall geological review of the deposits together with a recommended drilling program.

Additional work was conducted under contract and funded by the province to determine the most financially attractive alternative to consider for a feasibility study.

New Brunswick

The Canada-New Brunswick Mineral Development Agreements expired on March 31, 1989; the agreement provides a "wrap-up" year to allow for the completion of projects which were initiated during the agreement but were incomplete as of March 31, 1989.

A total of 11 projects, involving 15 contracts (Federal Delivery) have been initiated under the terms of the agreement; as of March 31, 1989, 11 of the contracts have been completed, and 4 will be completed during the wrap-up year 1989/90. The completion of the contracts will complete the federal government's funding commitment to the Mineral Development Agreement with New Brunswick.

During the current fiscal year, 1988/89, 10 projects, involving 11 contracts were managed; 6 of the contracts were on-going from previous years and 5 were let to initiate new projects. Seven projects have been completed as of the end of this fiscal year; they are: the Ferric Chloride Leach Project, the Manganese Processing Study, the Alkali Aggregate Reactivity Study, the Potash Mineralogy Study, the Use of Backfill in Potash Mines Study, the Utilization of CO_2 as an Engineering Control Parameter for Automated Mine Ventilation and the Dissolution of Gold and Silver in Cyanide Solutions at Sub-zero Temperatures. The remaining 4 projects will be completed during the wrap-up year 1989/90.

The new projects that were initiated in the 1988/89 fiscal year were: A Marketability Assessment of the CANMET Ferric Chloride Leach Process, Non-Destructive Testing of Mine Shaft Wire Ropes, Predictive Modelling of Subsidence Induced by Potash Mining, Fatigue Resistance of Light-Weight Concrete and Development of Instrumentation for Backfill Support Monitoring. A further project which has received approval, but for which a contract has not yet been let is the "Sulphide Ore Dust Explosion Control Investigation"; this study will be completed during the wrap-up year.

Newfoundland

During the 1988/89 period the effort in the Newfoundland MDA was directed mainly towards improved iron ore processing.

At Wabush Mines after Phases I (Mineralogy) and II (Batch Scale Tests) of the project Iron Ore Recovery were successfully completed, the mill line No. 4 at the Scully Mine Concentrator was transformed into a commercial scale pilot circuit. It includes an autogenous grinding mill equipped with trommel screen, sizing screens, rougher and cleaner spirals, pumps, tanks, valves, piping and some instrumentation.

This circuit was used for experimentation under the Phase III (Pilot Plant Test Work) and IV (Optimization of the Circuit).

Regrinding of spiral middlings (as recommended after bench scale results of Phase II were available) led to increase the weight recovery of the spiral product by 1.2%, while iron unit recovery rose by 1.8% without increasing the manganese grades. This means that the increase in weight recovery of the final concentrate will be about 1%. Such an increase on all mill lines will involve a net benefit to the mine of about $600K a year. There is a potential for further increase but more tests are required to assess the behaviour of manganese, the grade of which must stay low.

The flowsheet changes, as at the mill line No. 4, will be introduced to all mill lines. The mine is devoting $300K to implement our results.

Wabush Mines will introduce these changes following the maintenance schedule. Consequently, further mill lines will be modified by the end of February, in May/June, etc.

The next step within Phase III of our project consists of changing the screening/classification system. The mine has assigned $150K to buying the necessary equipment (screens, lining, etc.) which will be installed and tested using MDA money.

Phase IV, Optimization of the Circuit, mainly by introducing process control, has already started at the Iron Ore Company of Canada.

Defining and optimizing operating parameters of promising substitute organic binders with Carol Lake concentrate have been carried out. The best performance was obtained with a new version of Peridur called Peridur C-10. Test results indicate that an acceptable pellet quality can be achieved with this binder although economic factors are still to be considered by the company.

Although this project did not provide IOC with a pilot tested, ready to use technology, excellent batch scale results indicate that substitution of bentonite with an organic binder may be possible.

Within the project on Evaluation of Aggregates, a study on Alkali Reactivity continued.

Few of the many aggregates tested using the standard ASTM C 227 test have shown evidence of potentially deleterious expansion from alkali reactivity in concrete, despite occurrence of the reaction products in some field concretes containing similar rock types. It appears however, that at least arkosic sandstone aggregate could be reactive, and possibly some of the altered acidic volcanics. The Placentia Bay area gravels contain such rocks, which means caution is required if aggregate is chosen from there for marine structures.

Another study on Mechanical Properties and Long-Term Durability of Concrete with Local Aggregates and Cements for Potential Applications in Offshore Structures lead to developing a better knowledge of local high strength concrete mixtures.

The four non-mining related projects described above for which CANMET-MSL was responsible cost $280K during FY 1988/89.

Nova Scotia

There were 7 active projects during FY 1988/89. Work continued on the two largest projects, Alkali Reactivity of Aggregate, and Use of Fly Ash in Concrete. As a result of the fly ash study, use in the Maritime provinces has increased dramatically. A study on the conversion of Nova Scotia barite to barium chemicals was slowed because of the difficulties in obtaining a chemical grade feed from the Lake Ainslie deposits. A project on the production of magnetite from the Bass River deposit was completed, and a production decision is expected mid-1989. New projects were initiated in gold recovery from the Coxheath sulphide concentrate, narrow vein gold mining, and the removal of contaminants from old gold mine tailings effluents using biotechnology.

Expenditure by CANMET during 1988/89 was $365K. Five projects will continue into FY 1989/90, the "clean-up" year of the Canada-Nova Scotia Mineral Development Agreement. Total expenditure is expected to be equal to that of the original agreement, $3,275K.

Saskatchewan

The Minerals Technology component of the MDA continued with shared-cost contract work with the potash industry. During 1988/89, two contracts were undertaken: a study of the disposal of potash tailings, and basic research in brine control. The concept investigated on potash tailings disposal was the dissolution of waste tailings salts using water from a deep porous formation, and reinjecting a brine solution into the same formation. The results of the study were positive, the potash industry will do a pilot test starting late 1989. Brine inflow into the potash mines continues to be a priority concern for underground mining. The brine control study is examining various concepts such as solubility suppressants and modelling of stresses around mine openings and bulkheads.

The technology component of the Saskatchewan MDA ends March 1989. A total of nine projects were completed, eight of which were cost-shared with the potash industry. Total CANMET expenditure was $515,000, the amount of the MDA agreement.

PART B. GENERAL SERVICES AND OPERATIONS

CHEMICAL LABORATORY

Manager: H.F. Steger

Summary of Analytical Services

The figures tabulated below refer to the number of analyses performed by the Chemical Laboratory in support of CANMET programs in the period from 01 April 1988 to 31 March, 1989.

Sub-Activity	No. of Determinations	Sub-Activity	No. of Determinations
Mineral Processing			
30.05.03	228	30.61.05	29
30.05.99	85	30.61.99	676
30.13.02	20	30.69.01	55
30.13.04	52	30.69.02	609
30.13.07	630	30.69.99	62
30.13.99	551	30.77.01	73
30.21.02	1454	30.86.01	2415
30.21.99	788	30.86.03	1990
30.29.01	20	30.86.04	70
30.37.01	39	30.86.99	474
30.37.99	309		27191
30.45.01	329		
30.46.01	1893	**Metals & Materials**	
30.46.02	26		
30.46.03	4	70.04.03	1280
30.46.99	5	70.04.05	2
30.52.02	440	70.15.01	82
30.52.05	487	70.15.02	153
30.52.07	288	70.15.03	112
30.52.08	1807	70.42.01	16
30.52.09	2377	70.42.02	95
30.52.99	3295	70.42.03	36
30.61.01	230	70.42.05	11
30.61.02	5329	70.65.01	12
30.61.03	52	70.91.01	11
			1810

Total number of determinations = 29001

EXTRACTIVE METALLURGY LABORATORY

Physical Chemistry Section

Head: A.H. Webster

Thermal Analysis

Sub-Sub-Activity	No. of Tests
30.37	17
30.52	29
30.69	5
30.86	4
50.31	5
50.62	56
70.04	1
Total	117

Thermal analysis studies were conducted on behalf of the Canadian Conservation Institute and Alcan Research and Development.

Infrared Spectroscopy

Sub-Sub-Activity	No. of Tests
30.29	1
30.46	2
30.69	3
Total	6

Computer Programming

Databases on SYSTEM 2000 and FORTRAN programs on the EMR central computer facility are being converted to run locally on a microcomputer. The databases will use dBASE IV. Future plans call for the acquisition of graphics software and a tape backup system.

MINERAL PROCESSING LABORATORY

Process Mineralogy Section

Head: J.L. Jambor

Summary of Mineralogical Services

Project No.	Microprobe hours	SEM hours	X-ray films	X-ray diffractometer (jobs)
30.05.02	369.5			17
30.05.0[illegible]	195.5	16.5	20	
30.05.99	50.5	16.0	11	6
30.13.02			10	
30.13.99				3
30.21.01	18.0			4
30.21.02				54
30.21.99			3	10
30.29.01		5.0		104
30.37.99		6.5		11
30.45.01		9.0		
30.46.03			12	
30.52.05	109.5	121.0	59	35
30.52.07			12	1
30.52.08	9.0	141.5	508	451
30.52.09			7	5
30.61.02	25.0		14	62
30.61.99				1
30.69.99	3.5		-	-
30.86.01	12.0	43.5	109	20
30.86.02			6	1
30.86.03			67	11
30.86.04	69.0		27	105
30.86.99	53.0		4	7
50.62.06			15	12
Total	914.5	360.0	884	920

Lapidary, Mineral Separation and Other Services

Services	No. Completed
Polished Sections	970
Thin Polished Sections	17
Magnetic Separations	4
Crushing and Screen Analyses	93
Heavy Liquid Separations	56
Low-Temperature Ashing	2
Synthesis of Standards	4

INDUSTRIAL RESEARCH ASSISTANCE PROGRAM (IRAP)

Project No.	Project	Industry	Scientific Authority
L2730-0722	Enhanced Recovery of Asbestos Fibre Using Wet Milling Process	Cassiar	D.M. Doyle
L2730-0870	D.C. Plasma Arc Furnace	Inco Ltd.	J.M. Skeaff
L2730-0969	Column Flotation of Lead and Zinc Sulphides	Cominco Ltd.	D.M. Doyle
L2730-1078	Chara Process: Biological Polishing of Alkaline Effluents	Boojum	R.G.L. McCready
L2730-1107	Nitrate Based Gold Recovery (NITFAUR Process)	Hydrochem	K.E. Haque
L2730-1184	Process Control and Expert System for Oil Sand Extraction	Syncrude/Edmonton	D.M. Doyle
L2730-1199	Recovery of Platinum, Palladium, and Rhodium from Spent Automotive Catalysts	Platinum Lake	R.E. Molnar
L2730-1202	Improved Iron Recovery	Iron Ore Company of Canada	W.H. Cameron
L2730-1264	Agitated Flotation Column	Hydrochem	T. Cienski
L2730-1331	Image Analysis for Oilwells	Petrel	D. Leckie (EMR/ISPG)
L2730-1351	Development of Beryllium Chemical Plant Technology	Hecla	K.E. Haque
L2730-1367	On-Stream Cyanide Analyzer	Corrigan	F.J. Kelly
L2730-1376	Value Added Graphite Products	Stewart Lake	D.G. Feasby
L2730-1377	Portable Ultrasonic Concrete Tester	Techno	V.M. Malhotra
L2730-1395	Gold Recovery by Ion Exchange	I.W.T. Himsley	P. Riveros
L2730-1451	Mackie Vat Leaching Jig	H.G.E. Inc.	R.J.C. MacDonald

COST RECOVERY CONTRACTS

General

Cost Recovery No.	Project Leader	Title
25545	W. Craigen	Evaluating tax payer's claims on scientific research

Chemical Laboratory

Cost Recovery No.	Project Leader	Title
25528	H. Steger	Emission spectrometric analysis of titanium dioxide
25531	C. Smith	Preparation of gold-bearing rock reference samples
25535	D. Barkley	Analysis of strontium carbonate/oxide samples
25544	C. Smith	Preparation of plantiniferous ore concentrate reference material
25548	L. Dalton	Determination of radioactivity of by-product from titanium-oxide production
50003	H. Steger	Precious metal analysis-Alcan bauxites and red muds
50004	H. Steger	Use of MSL gamma spectrometer
50034	H. Steger	Preparation of solution samples

Extractive Metallurgy Laboratory

Cost Recovery No.	Project Leader	Title
00000	W. Gould	Biodegradation of an industrial organic
00000	R. McCready	Training in microbiology
25507	D. Shimamo	Dewatering and calcining of lime
25514	J. Skeaff	Arc furnace smelting of molybdenum bearing catalyst
25529	V. MacNamara	Cyanide and metals recovery from Merrill-Crowe barren solutions
25532	R. Molnar	Evaluation of ion exchange resins
25550	G. Ritcey	Consultation on reagents to assist in the removal of calcium and magnesium from solution
50002	R. Molnar	Iron removal from zinc sulphate liquor
50006	D. MacKinnon	Zinc electrowinning
50015	R. McCready	Biodegradation of deicing fluids
50016	R. McCready	Field test of acid drainage mitigation using microbial decomposition of wood waste
50019	R. McCready	Microbiological analysis of QCM circuit
50048	R. Molnar	Development of beryllium chemical plant technology
50049	R. McCready	Biotreatment technology
50074	R. McCready	Advisor to consult on microbiology study
50079	J. Skeaff	Dielectric development program for air purification systems based on ozone

Mineral Processing Laboratory

Cost Recovery No.	Project Leader	Title
25288	P. Mainwaring	Mineralogical analysis
25289	W. Petruk	Transfer of image analysis technology to the New Brunswick Research Productivity Council
25503	P. Mainwaring	Mineralogical analysis on goldstrike ore
25516	M. Cristovici	Upgrading and pelletizing ilmenite ore fines from QIT
25525	L. Cabri	Analyses from Tulameen chromite
25527	D. Laguitton	Process control and expert system for oil
25534	P. Mainwaring	Mineralogical analysis for the Iron Ore Company
25546	D. Quon	Reaction of strontium-carbonates with alumina refractory
25547	M. Raicevic	Mineral processing investigation on Alcan smelter dust
50000	J. Jambor	Mineralogical examination of synthetic carbon-alumina samples
50001	V. Malhotra	Utilization of waste from fluidized-bed operations as a cementitious material
50005	G. Feasby	Analysis of graphite sample from Labrador
50007	G. Feasby	Recovery and examination of koalin in a koalin-silica deposit
50008	T. Wheat	Determination of pyrometric cone equivalent (PCE) of refractory materials
50009	M. Stefanski	Development of asbestos grade control monitor
50010	P. Mainwaring	Mineralogical investigations related to gold occurrence and association in cyanidation and flotation circuits
50014	J. Soles	Examination of finished surface layers of concrete to evaluate the matrix, the reduction of dust formation and surface deterioration
50017	J. Szymanski	X-ray diffraction analysis of pitch ash
50020	V. Malhotra	Sealing pyritic slate outcrops
50021	L. Cabri	Improved understanding on the amount and nature of microscopic gold
50022	L. Cabri	Sphalerite floatability
50024	P. Mainwaring	Liberation analysis of Winston Lake mill feed
50025	L. Cabri	Mineralogical examination of the platinum group elements
50030	J. Canaday	Investigation of Hyceram for sensor applications
50031	G. Mathieu	Separation of pyrite from black pyrochlore
50032	J. Jambor	Mineralogical investigation of samples from the Lake Zone of the Thor Lake deposit, NWT

Mineral Processing Laboratory (Cont'd)

Cost Recovery No.	Project Leader	Title
50033	J. Wilson	Mineralogical analysis of the Faro plant
50037	P. Mainwaring	Training on the image analyzer
50038	G. Feasby	Wollastonite beneficiation
50043	G. Feasby	Dolomite decrepitation sand extraction
50044	D. Quon	Calcination of clay samples
50046	W. Petruk	Preparation of copper tailings samples for analysis on image analyzer
50050	T. Cienski	Column flotation investigation on Trout Lake copper concentrate
50051	L. Cabri	Electron microprobe analysis of platinum minerals
50052	G. Feasby	Gold tailings, screening, assaying
50053	G. Feasby	ASTM tests on granite samples
50055	T. Cienski	Column flotation investigation on primary cyclone overflow
50057	V. Malhotra	Foam concrete
50058	G. Carette	Determination of physical and mechanical properties of natural building stone samples
50059	W. Cameron	Training in techniques of froth flotation related to mineral beneficiation
50060	M. Bilodeau	Training on the circuit simulator (SIMBAL) software program
50063	D. Laguitton	Training on the material balance (MATBAL) software program
50064	J. Canaday	Preparation of hydronium sample
50067	M. Raicevic	IOC flux recovery by Sala HGMS
50068	W. Petruk	Image analysis study on copper tailings
50070	P. Mainwaring	Image analysis for oilwells
50075	G. Feasby	Dolomite comparison
50077	G. Mathieu	Techniques de nettoyage d'un chargement de coke contamine par la magnatite

VISITING SCIENTISTS

Extraction Metallurgy Laboratory

Dr. David Muir, Murdoch University, Perth, Australia, June-September 1988.

Dr. Patricio Riveros - Post-Doctoral Fellow from Chile, April 1988-January 1989.

Dr. Farouk Awadella - Post-Doctoral Fellow from Egypt, January 1988.

Chemical Laboratory

Mrs. Madia Youssef Mohammed of the Egyptian Atomic Energy Agency was a visiting scientist in the Chemical Laboratory from May to August, 1988, under the sponsorship of the International Atomic Energy Agency.

Dr. Jamal A. Sweileh is a Post-Doctoral Fellow, Ph.D. from University of Alberta, from December 1987-November 1989.

Mineral Processing Laboratory

Dr. Samir Chehab (May 1988); NSERC Visiting Fellow; Preparation and Characterization of Advanced Ceramics.

Dr. Marian Smith (November 1986-September 1988); NSERC Visiting Fellow; Mineralogical Evaluation of Process Products.

Mr. Luis Fernandez Luco (April 1988-September 1988); IDRC Sponsored Visiting Fellow (Argentina); Supplementary Cementing Materials.

Mr. German Caguana (February 1988); IDRC Sponsored Visiting Fellow (Ecuador); Beneficiation of Industrial Minerals.

Mr. Nick Maffei (1984); Secondment from B.M. Hi-Tech Inc.; Preparation and Characterization of Advanced Ceramics.

Dr. Mohammed Saleem (November 1987); Secondment from Ceramics Kingston; Preparation and Characterization of Advanced Ceramics.

Dr. Mohamed Alkali (December 1987); NSERC Visiting Fellow; Alkali Aggregate Reactivity (in Concrete).

CANMET SEMINAR IN TIMMINS

Seminar "CANMET, Partner with the Ontario Mining Industry" was held in Timmins, Ontario on November 22nd and 23rd, 1988.

The main objective of this CANMET organized seminar was to establish a more direct contact with the Ontario mining community, particularly mines in Northeastern Ontario and in Northwestern Quebec.

The seminar attendance was good (80), the participants coming mainly from the mining operations in the Timmins area.

The principal form of the seminar were:

- paper presentations
- discussions
- demonstrations and exhibits by CANMET staff
- workshops

The areas covered during the general session and during more specialized MTL, MRL and MSL sessions were:

- mine health and safety
- ground control
- surface crown pillars
- backfilling
- corrosion in the mining industry
- welding techniques
- optimization and control in ore dressing
- experts systems in mineral processing
- research in gold extraction methods
- image analysis and mineralogy
- mining environment
- financial support programs for research and development

A total of 26 technical papers were presented at the sessions while various MRL and MSL demonstrations took place in the exhibit area. CANMET publications such as the MSL Annual Report 1987/88, project reports, fact sheets, etc. were received with a high degree of interest.

The seminar provided an effective forum for the exchange of ideas between the government researchers and mining industry representatives.

PART C. REPRESENTATION ON TECHNICAL COMMITTEES

INTERNATIONAL

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

Barkley, D.J.
- Member, CAC/ISO/TC 26/SC 1, Copper and Copper Alloys;
- Member, CAC/ISO/TC 17/SC 1, Analysis of Steel and Cast Iron;
- Corresponding Partner, CAC/ISO/TC 17/SC 1/WG-12, Plasma.

Graham, J.A.
- Member, CAC/ISO/TC 183, Copper, Lead and Zinc Ores and Concentrates;
- Member, CAC/ISO/TC 183, Hosting Committee for the International Conference in Ottawa, May, 1988;
- Corresponding Partner, CAC/ISO/TC 183/WG-2, Silver and Gold in Copper Concentrates.

Hole, J.C.
- Member, CAC/ISO/TC 102, Iron Ores;
- Chairman, CAC/ISO/TC 102/SC 2, Iron Ores.

Mainwaring, P.R.
- Member, Joint CAC/ISO/TC 146/147/SC 3, WG1, Detection Asbestos Fibre in Air.

Malhotra, V.M.
- Chairman, CAC/ISO/TC 71, Concrete (SC 1 and SC 3).

Smith, C.W.
- Member, CAC/ISO/REMCO, Committee on Reference Materials.

Steger, H.F.
- Chairman, CAC/ISO/REMCO, Reference Materials.

Sutarno, R.
- Member, CAC/ISO/TC 102, Iron Ore;
- Chairman, CAC/ISO/TC 102/SC 1, Sampling Subcommittee;
- Convener, ISO/TC 102/SC 2/WG 12, Chemical Analysis Subcommittee, Working Group on Evaluation of Statistical Data;
- Member, CAC/ISO/TC 69, Application of Statistical Methods;
- Chairman, CAC/ISO/TC 69/SC 6, Measurement Methods and Results;
- Canadian Representative to ISO/TC 69/SC 6/WG 1, Revision of ISO 5725;
- Convener, ISO/TC 69/SC 6/WG 4, Statistical Aspects of Reference Materials;
- Member, CAC/ISO/REMCO, Reference Materials;
- Member, CAC/ISO/TC 183, Copper, Lead and Zinc Ores and Concentrates;
- Convener, ISO/TC 183/WG 10, Statistical Evaluation of Test Programs.

Wilson, J.M.D.
- Member, CAC/ISO/TC 24, Sieves, Sieving and Other Sizing Methods;
- Member, CAC/ISO/TC 102, Iron Ores (SC 3 and SC 5).

ISO/TC 183 INTERNATIONAL MEETING

The biennial meeting of the International Organization for Standardization Technical Committee 183 (ISO/TC 183), which is charged with the development of standards for copper, lead and zinc ores and concentrates, was held in Ottawa at the Government Conference Centre, May 16-20, 1988. Four MSL representatives participated in this meeting in various capacities: as accredited members of the Canadian delegation along with representatives from industry, as members of the organizing committee, and as translator. Dr. M.D. Everell gave the keynote address at the banquet held during the meeting.

INTERNATIONAL MINERALOGICAL ASSOCIATION

Cabri, L.J.
- Canadian Representative, Commission of Ore Microscopy;
- Rapporteur, Analytical Methods Subcommittee, Commission of Applied Mineralogy.

Chen, T.T.
- Member, Committee on Sulphosalts.

INTERNATIONAL COMMITTEE ON APPLIED MINERALOGY IN THE MINERAL INDUSTRY

Petruk, W.
- Canadian Representative;
- Liaison Representative.

INTERNATIONAL ATOMIC ENERGY AGENCY

Campbell, M.C.
- Member, Consultants Group on Uranium Extraction.

Dalton, J.L.
- Consultant, Analytical Techniques in Uranium Exploration, Development and Ore Processing.

MISCELLANEOUS

Dutrizac, J.E.
- Member, Editorial Board, Hydrometallurgy, Elsevier Publishing Co., Amsterdam;
- Secretary, Copper 91-Colore 91 International Copper Conference.

MacKinnon, D.J.
- Member, Editorial Board, Hydrometallurgy, Elsevier Publishing Co., Amsterdam.

McCready, R.G.L.
- Member, Editorial Board, Hydrometallurgy, Elsevier Publishing Co., Amsterdam;
- Alternatve Member of the Biotechnology Coordinating Group, National Biotechnology Strategy;
- Co-chairman of the 9th International Symposium on Biohydrometallurgy, Jackson Hole, WO, August 13-18, 1989.

Malhotra, V.M.
- Member, Committee on NDT of Concrete.

Mirkovich, V.V.
- Director, International Thermal Conductivity Conference;
- Member, Editorial Board, International Journal of Thermophysics, Plenum Press, N.Y.

Ritcey, G.M.
- Member, International Solvent Extraction Technology Committee;
- Editor, International Journal of Hydrometallurgy, Elsevier Pub. Co., Amsterdam;
- Member, Editorial Board, Journal of Separation Process Technology, C. Lildwell Press, England;
- Member, Editorial Board, "Science and Technology of Tributyl Phosphate", C.R.C. Press, Pub.;
- Member, Editorial Board, "Extractive and Process Metallurgy", Gorden & Branch, Pub.;
- Member, International Conference on Separation Science and Technology-International Committee;
- Chairman, International Conference on Separation Science and Technology, Second Conference.

Sirois, L.L.
- Member, International Scientific Committee of the International Mineral Processing Congress;
- Member, 10th International Coal Preparation Congress, Organizing Committee.

Stefanski, M.J.
- Member, 10th International Coal Preparation Congress, Technical Program Committee.

Szymanski, J.T.
- Secretary to the Canadian National Committee to the International Union of Crystallography.

CANADA

FEDERAL

Andrews, P.R.A., Doyle, D., Lamothe, J.M., Soles J.A., Wang, S.S.B., Wilson, H.W.
- Members, Interbranch Liaison, Industrial Minerals (ILIM).

Bedard, P.
- Member, MSL-EDP Committee.

Bell, D.H.
- Co-chairman, Technical Subcommittee for Mining and Mineral Technology, CANADA/NEWBRUNSWICK Mineral Development Agreement.

Campbell, M.C.
- Chairman, BIOMINET;
- Chairman, MSL-EDP Committee;
- Member, CANMET EDP Acquisitions Committee;
- Member, Uranium Resource Appraisal Group;
- Member, Biotechnology Co-ordinating Group.

Collings, R.K.
- Chairman, Interbranch Liaison, Industrial Mineral (ILIM).

McCready, R.G.L.
- Secretary, BIOMINET.

Stefanski, M.
- Co-chairman, Technical Subcommittee for Mining and Mineral Technology, CANADA/NEWFOUNDLAND Mineral Development Agreement.

Steger, H.F.
- Member, Interdepartmental Committee on Standards Policy.

Sutarno, R.
- Member, MSL-EDP Committee;
- Member, CANMET EDP Acquisitions Committee.

DEPARTMENT OF REGIONAL INDUSTRIAL EXPANSION

Craigen, W.J.S.
- Member, Technical Advisory Committee for the Canada - New Brunswick Sulphation Roast Leach Pilot Plant;
- Member, Board of Directors for Enhanced Recovery Systems (ERS);
- Member, Technical Advisory Committee for Northern Smelters Modernization.

CANADA GENERAL STANDARDS BOARD

Douglas, E.
- Member, Committee GP-34, Asbestos-Cement Products.

UNIVERSITY OF BRITISH COLUMBIA
THE CENTRE FOR METALLURGICAL PROCESS DEVELOPMENT

Campbell, M.C.
- Member, Technical Advisory Board.

ENVIRONMENT CANADA

Joe, E.G.
- Member, Gold Processors Working Group.

NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL

Dutrizac, J.E.
- Member, Grant Selection Committee, Chemical and Metallurgical Engineering;
- Member, Strategic Grants Committee, Mineral Resources.

Townsend, M.G.
- Member, Committee on Technology for Silicon Integrated Circuits.

Wilson, L.J.
- Scientific Secretary, Grant Selection Committee, Interdisciplinary.

MISCELLANEOUS

CANADIAN CERAMIC SOCIETY

Ahmad, A.
- Member, Electronics and Basic Science Division;
- Chairman, Electronics and Basic Science Division, Technical Sessions;
- Judge, Ceramographic Competition.

Canaday, J.D.
- Associate Editor, Journal of Canadian Ceramic Society.

Kuriakose, A.K.
- Chairman, Ceramographic Committee;
- Associate Editor, Journal of CCS;
- Director, C.C.S.;
- Session Chairman, CCS Annual Meeting, Electronics and Basic Sciences Division.

Wheat, T.A.
- Director, Electronics Basic Science Division;
- Chairman, Publications Committee.

CANADIAN COMMITTEE ON ANALYTICAL CHEMISTRY RELATED TO CANADA'S NUCLEAR INDUSTRY

Dalton, J.L.
- Member, Workshop Organizing Committee.

CANADIAN INSTITUTE OF MINING AND METALLURGY

Collings, R.K.
- Member, Special Volumes Committee.

Doyle, D.
- Secretary, Canadian Mineral Processors Division;

Dutrizac, J.E.
- Member, Historical Metallurgical Committee;
- Member, Light Metals Committee;
- Publicity Chairman, 1990 Hydrometallurgical Meeting.

Jambor, J.L.
- Chairman, Barlow Memorial Award Committee; Vice-Chairman-Elect, Geology Division.

Laguitton, D.
- Member, Computer Applications and Process Control Committee.

Mainwaring, P.R.
- Chairman, Mineral Sciences and Engineering Section, Metallurgical Society.

Ritcey, G.M.
- Member, Hydrometallurgy Section Executive.

Skeaff, J.M.
- Publicity Chairman, 1988 CIM Conference of Metallurgists.

Tan, K.G.
- Member, Hydrometallurgy Section Executive.

CANADIAN MINERAL PROCESSORS CONFERENCE

Doyle, D.
- Secretary.

CANADIAN NATIONAL COMMITTEE FOR THE INTERNATIONAL UNION OF CRYSTALLOGRAPHY

Szymanski, J.T.
- Secretary.

CANADIAN STANDARDS ASSOCIATION

Andrews, P.R.A.
- Member, Committee on Gypsum and Lime (A.82);
- Chairman, Editorial Subcommittee.

Carette, G.G.
- Member, Committee on Cement (A.5);
- Member, Committee on Cement Admixtures.

Malhotra, V.M.
- Member, Executive Committee on Aggregates and Concrete (A.23.1, A.23.2, A.24.3);
- Member, CSA Committee (A.23.1).

Soles, J.A.
- Member, Subcommittee on Cement-Aggregate Reactivity.

Sutarno, R.
- Member, Committee on Applications of Statistical Methods.

CANADIAN SOCIETY OF CIVIL ENGINEERING

Malhotra, V.M.
- Member, Technical Activities Committee;
- Associate Editor, Canadian Journal of Civil Engineering.

CANADIAN URANIUM PRODUCERS'S METALLURGICAL COMMITTEE

Dalton, J.L.
- Secretary-Treasurer, Analytical Subcommittee;
- Convenor, ICP-OES Course, Saskatchewan Research Council, Saskatoon.

CHEMICAL INSTITUTE OF CANADA

Hole, J.C.
- Chairman, Committee of Scrutineers.

IRON ORES PROCESSORS TASK FORCE

Cameron, W.
- Chairman and Secretary.

Campbell, F.R., Doyle, D., Kuriakose, A.K., Quon, D., Stefanski, M.J., Wilson, J.M.D.
- Members.

MINERALOGICAL ASSOCIATION OF CANADA

Cabri, L.J.
- Member, Past Presidents' Medal Committee.

Jambor, J.L.
- Acting Editor-in-Chief, The Canadian Mineralogist.

Szymanski, J.T.
- Associate Editor, The Canadian Mineralogist.

SPECTROSCOPY SOCIETY OF CANADA

Churchill, T.R.
- Business Manager, Canadian Journal of Spectroscopy.

Wittwer, J.W.
- Director, Ottawa Valley Section.

TECHNICAL COMMITTEE ON ACID MINE DRAINAGE

McCready, R.G.L.
- Member, (Intnl. Airport Halifax).

UNITED STATES OF AMERICA

AMERICAN CONCRETE INSTITUTE

Malhotra, V.M.
- Member, Technical Activities Committee;
- Member, ACI Committee 114 on Research Needs in Concrete;
- Chairman, ACI Committee 226/Subcommittee on Silica Fume;
- Member, Materials Research Council;
- Member, Technical Committee (214, 226, 228 and 568).

AMERICAN INSTITUTE OF MINING, METALLURGICAL AND PETROLEUM ENGINEERS

Dutrizac, J.E.
- Member, Lead, Zinc, Tin Committee;
- Member, Organizing Committee, Lead-Zinc '90 World Symposium.

Petruk, W.
- Chairman, Process Mineralogy Committee.

AMERICAN SOCIETY FOR TESTING AND MATERIALS

Horton, R.E.
- Secretary, Committee E.02, Analytical Atomic Spectroscopy;
- Leader, Task Group on Line Overlap in X-ray Spectrometry.

Malhotra, V.M.
- Member, Committee C.09, Concrete;
- Chairman, C.09.02.05, Subcommittee on Non-Destructive Testing of Concrete.

Sutarno, R.
- Member, Committee E03.16, Sampling and Analysis of Metal-Bearing Ores and Related Materials;
- Member, Working Group on Sampling.

AMERICAN CERAMIC SOCIETY

Ahmad, A.
- Member, The Basic Science Division.

Kuriakose, A.K.
- Member.

MINERALOGICAL SOCIETY OF AMERICA

Jambor, J.L.
- New Minerals Editor, The American Mineralogist.

NATIONAL RESEARCH COUNCIL, U.S.A. - TRANSPORTATION RESEARCH BOARD

Malhotra, V.M.
- Chairman, Committee A2 E.03, Mechanical Properties of Concrete.

CENTER FOR RESEARCH ON SULPHUR IN COAL

Moon, K.S.
- Member, Program Review Committee.

SOCIETY OF ECONOMIC GEOLOGY

Jambor, J.L.
- Member, Thayer Lindsley Visiting Lecture Committee.

PART D. PUBLICATIONS, PAPERS, PRESENTATIONS AND REPORTS

Articles and Chapters Published in Books

Barkley, D.J. and Dahms, T.E., "The analysis of rare earths in steels and Nd-alloy by dynamic ion-exchange chromatography"; in Recent Developments in Ion Exchange; Edited by P.A. Williams and M.J. Hudson; Elsevier Applied Science 396-401; London, England; 1988.

Lakshmanan, V.I., Heinrich, G. and McCready, R.G.L., "Stabilization of biomass for the removal of uranium from diluted solutions by biosorption"; in Biotechnology in Minerals and Metals Processing 23:187-192; AIME; Las Vegas; 1989.

McCready, R.G.L., "Progress in the bacterial leaching of metals in Canada"; in Biohydrometallurgy; Edited by P.R. Norris and D.P. Kelly; Antony Rowe Ltd. 177-195; Chippenham, England; 1988.

McCready, R.G.L., "Microbiological studies on high-sulphur eastern Canadian coals"; in Bioprocessing and Biotreatment of Coal; Edited by D.L. Wise, Marcel Dekker Inc., N.Y. (in Press).

McCready, R.G.L. and Gould, W.D., "Bioleaching of uranium"; in Microbial Mineral Recovery; Edited by H.L. Erlich, McGraw-Hill Ltd. (in Press); 1989.

Murray, E.W., Goudey, S.P., McCready, R.G.L. and Salley, J., "Laboratory and field testing of a salt-supplemented clay cap as an impermeable seal over pyritic slates"; in Mine drainage and surface mine reclamation; Bureau of Mines Information Circular IC 9183; 1:52-58; 1988.

Book Reviews

Donaldson, E.M., "Analytical Chemistry in the Exploration, Mining and Processing of Materials"; L.R.P. Butler (Editor); Blackwell Scientific Publications, 254 pages; Oxford, England; 1986; review in Talanta 35:i; 1988.

Donaldson, E.M., "Assay and Analytical Practice in the South African Mining Industry"; W.C. Lenahan and R. de L. Murray-Smith; South African Institute of Mining and Metallurgy, 640 pages; Johannesburg, South Africa; 1986; review in Talanta 35:i; 1988.

Papers Published in Conference Proceedings

Cabri, L.J., "Overview on application of platinum mineralogy to mineral exploration and processing"; In: Process Mineralogy VIII, AIME/TMS; January 1988 (in Press).

Cabri, L.J., "The role of mineralogy in gold metallurgy"; Proc. Symposium on Heap Leaching in a Canadian Environment; CMP/CIM; Paper No. 2; Timmins; 1988.

Cabri, L.J., "New developments in determination of the distribution of precious metals in ore deposits"; In: Proc. 7th Quadrennial IAGOD Symposium 149-154; 1988.

Deschênes, G. and Ritcey, G.M., "New developments in gold recovery and purification"; Proceedings of the 19th Ann. Meeting of the Canadian Mineral Processors 526-55[illegible]; Ottawa; January 1987.

Deschênes, G., "Investigation on the potential techniques to recover gold from thiourea solution"; Proceedings of the International Symposium on Gold Metallurgy 359-377; Winnipeg; August 1987.

Deschênes, G., "Progrès et orientation de la recherche et du développement de l'industrie aurifère"; Actes du 2ième colloque sur l'or du centre de recherches minérales du Québec"; Rouyn-Noranda 95-120; Novembre 1987.

Deschênes, G., "Techniques de récupération de l'or d'une solution"; Proceedings of the CANMET Seminar 270-294; Val d'Or; February 1988.

Deschênes, G., "Development and applications of thiourea for processing gold deposit"; Proceedings of the CANMET Seminar 508-536; Timmins; November 1988.

Dutrizac, J.E. and Chen, T.T., "A mineralogical comparison of the anode slimes from three Canadian copper refineries"; Copper '87; eds. W.C. Cooper, G.E. Lagos and G. Ugarate; University of Chile 3:467-486; 1988.

Gould, W.D., McCready, R.G.L., Rajan, S. and Krouse, H.R., "Stable isotope composition of sulphate produced during the bacterial oxidation of various metal sulphides"; Proceedings of the Can. Soc. of Microbiol. Ann. Mtg., Windsor, Ontario; June 1988.

Gould, W.D., McCready, R.G.L., Salley, J., Rajan, S., Chalykoff, C. and Beaudette, L., "Microbial treatment of industrial effluents"; Proceedings of the 1988 Annual BIOMINET Meeting; 1988.

Haque, K.E., "A review of CANMET's acid chloride leaching of uranium ores"; Proceedings of the Uranium and Electricity Symposium held in Saskatoon, Sask.; September 1988.

Haque, K.E., "Radium(226) removal from a contaminated soil"; Proceedings of the US-EPA Workshop in Extractive Treatment of Excavated Soil, Edison, N.Y.; December 1988.

Haque, K.E., "The pretreatment options for refractory gold concentrate"; Proceedings of the CANMET Seminar at Timmins; November 1988.

Haque, K.E. and Cienski, T., "Alkaline cyanide leaching of gold ores"; Proceedings of the CANMET Seminar held in Val d'Or, Quebec; February 1988.

Lakshmanan, V.I., King, D.J., Tsezos, M. and McCready, R.G.L., "Optimization of fungal adsorption of uranium and cell immobilization"; BIOMINET Proc. 119-134; CANMET SP 87-10; 1987.

Malhotra, V.M., "New materials for quality concrete"; Proceedings at the Fifth Building and Construction Congress, Montreal; November 1988.

Malhotra, V.M., Carette, G.G. and Bremner, T.W., "Current status of CANMET studies on the durability of concrete containing supplementary cementing materials in marine environment"; Proceedings of the 2nd CANMET/ACI International Conference on Performance of Concrete in Marine Environment, St. Andrews, N.B.; August 1988.

Malhotra, V.M., "Use of fly ash, slag and silica fume in North America and Europe"; Proceedings of the International Workshop on the Use of Fly Ash, Slag, Silica Fume and Other Siliceous Materials in Concrete, Sydney, Australia; July 1988.

McCready, R.G.L., Salley, J., Hoppe, D.G. and Bartlett, D.R., "Progress on emulsification and flotation as a means of upgrading a Cu/Mo concentrate"; BIOMINET Proc. 147-155; CANMET SP 87-10; 1987.

McCready, R.G.L., Salley, J. and Smith, T.G., "Biorecovery of selenium"; BIOMINET Proc. 135-146; CANMET SP 87-10; 1987.

McCready, R.G.L., "A review of the physical, chemical and biological measures to prevent acid mine drainage: An application to the pyritic Halifax shales"; Proceedings of the Acid Mine Drainage Seminar/Workshop 333-355; Environment Canada; En 40-11-7; 1987.

McNamara, V.M. and Ritcey, G.M., "Cyanide abatement processes for gold mill effluent treatment"; Presented at Timmins '88 and Val d'Or '88 CANMET Seminars on Gold Research and published in the respective proceedings; 1988.

McNamara, V.M., "The AVR process for cyanide recovery, and cyanogen control for barren recycle and barren bleed"; Proceedings at the Vancouver, February 1989 and Toronto, March 1989 at Seminars on Gold Mill Treatment of Effluent sponsored by Environment Canada and the B.C. and Ontario Mining Associations, respectively.

Mikhail, S.A., Turcotte, A.M. and Bowman, W.S., "A study of the decomposition of higher cobalt aresenides by thermal analysis"; Proceedings of the 17th North American Thermal Analysis Society Conference; ed. C.M. Earnest; 46-52; 1988.

Miller, D.S., Eby, N., McCorkell, R.H., Rosenberg, P.E. and Suzuki, M., "Results of interlaboratory comparison of fission-track ages for 1988 Fission Track Workshop"; Proceedings of the Fission-Track Workshop; Besancon, France; 1988.

Nawwar, A.M. and Malhotra, V.M., "Development of a test method to determine the resistance of concrete to ice abrasion and/or impact"; Proceedings of the 2nd CANMET/ACI International Conference on Performance of Concrete in Marine Environment, St. Andrews, N.B.; August 1988.

Petruk, W., "Recent progress in mineralogical investigations related to gold recovery"; Timmins, CANMET and Ontario Mining Association Meeting; November 24, 1988.

Riveros, P.A., "Advance in ion exchange and solvent extraction for gold recovery"; Proceedings at Timmins '88 CANMET Seminar on Gold Research and Publication in the Proceedings; November 1988.

Sanmugasunderam, V., Gould, W.D., McCready, R.G.L., Rajan, S., Beaulne, M. and Mainwaring, P., "Bacterial and chemical leaching of complex sulphide ores"; BIOMINET Proc. 103-117; CANMET SP 87-10; 1987.

Scoates, R.F.J., Eckstrand, O.R. and Cabri, L.J., "Interelement correlation, stratigraphic variation and distribution of PGE in the Ultramafic Series of the Bird River sill, Canada"; In: Geo Platinum 87; 239-252; 1988.

Wilson, L.J. and Mikhail, S.A., "Investigation of the oxidation of skutterudite by thermal analysis"; Proceedings of the 17th North American Thermal Analysis Society Conference; ed. C.M. Earnest; 53-59; 1988.

Papers Published in Outside Journals

Ahmed, S.M., Leduc, J. and Haller, S.F., "Photoelectrochemical and impedance characteristics of specular hematite. 1. Photoelectrochemical, parallel conductance, and trap rate studies"; J. Phys. Chem. 92:6655-6660; 1988.

Ahmed, S.M., Leduc, J. and Trudel, J., "Studies of the field dependent photoluminescence of n-GaAs electrodes with and without cobalt films"; J. Electrochem. Soc. 135:3015-3022; 1988.

Chen, T.T. and Dutrizac, J.E., "Application of electron microscopy to the electrorefining of copper"; Scanning Microscopy 2:2:735-746; 1988.

Chen, T.T. and Dutrizac, J.E., "Mineralogical characterization of anode slimes: Part 1 - Anode copper from Inco's Copper Cliff Copper Refinery"; Canadian Metal. Quart. 87:2:91-96; 1988.

Chen, T.T. and Dutrizac, J.E., "Mineralogical characterization of anode slimes: Part 2 - Raw anode slimes from Inco's Copper Cliff Copper Refinery"; Canadian Metal. Quart. 87:2:97-105; 1988.

Chen, T.T. and Dutrizac, J.E., "Mineralogical characterization of anode slimes: Part 3 - Sulphation reactor slimes from Inco's Copper Cliff Copper Refinery"; Canadian Metal. Quart. 87:2:107-116; 1988.

Chen, T.T. and Dutrizac, J.E., "Mineralogical characterization of silver flotation concentrates made from zinc neutral leach residues"; Metal. Trans. 19B:803-817; 1988.

Craigen, W.J.S., Krysa, B.D., Brown, H.H. and Barlin, B., "Evaluation of the Great Central Mines (GCM) hydrometallurgical copper process for application to Hudson Bay Mining and Smelting (HBMS) copper concentrates"; Paper published in Proceedings of the CIM 18th Annual Hydrometallurgy Meeting; Edmonton, Alberta; May 1988.

Deschênes, G. and Ghali, E., "Leaching of gold from a chalcopyrite concentrate by thiourea"; Hydrometallurgy 20:170-202; 1988.

Donaldson, E.M., "Determination of arsenic in ores, concentrates and related materials by graphite-furnace atomic-absorption spectrometry after separation by xanthate extraction"; Talanta 35:47-53; 1988.

Donaldson, E.M. and Leaver, M.E., "Determination of arsenic in ores, concentrates and related materials by continuous hydride-generation atomic-absorption spectrometry after separation by xanthate extraction"; Talanta 35:297-300; 1988.

Donaldson, E.M., "Determination of selenium in ores, concentrates and related materials by graphite-furnace atomic-absorption spectrometry after separation by extraction of the 4-nitro-o-phenylenediamine complex"; Talanta 35:633-639; 1988.

Dutrizac, J.E., "Still further observations on Canada's first cyanide leaching plant: Early Ontario operations"; CIM Bull. 81:911:157-161; 1988.

Dutrizac, J.E. and Jambor, J.L., "The behaviour of silver during jarosite precipitation"; Trans. I.M.M. 96:C206-C217; 1987.

Dutrizac, J.E. and Jambor, J.L., "The synthesis of crystallized scorodite, $FeAsO_4 \cdot 2H_2O$"; Hydrometallurgy 19:377-384; 1988.

Grasty, R.L., Franklin, J.M., Jonasson, I.R. and Smith, C.W., "Radioactive orphans in barite-rich chimneys, axial caldera, Juan de Fuca ridge"; Can. Mineral 26:627-636; 1988.

Haque, K.E., "Acid chloride leaching of Midwest Lake Uranium ore" (Northern Saskatchewan, Canada)"; Uranium 4:261-273; 1988.

Hogarth, D.P., Rushford, P. and McCorkell, R.H., "The Blackburn carbonatites near Ottawa, Ontario: Dykes with fluidized emplacement"; Can. Mineral 26:377-390; 1988.

Jambor, J.L. and Dutrizac, J.E., "Synthesis of the ferric analog of the ferrous-ferric phosphate, giniite"; Neues Jahrbuch. Miner. Abh. 159:1:51-58; 1988.

Leduc, J. and Ahmed, S.M., "Photoelectrochemical and impedance characteristics of specular hematite. 2. Deep bulk traps in specular hematite at small alternating-current frequencies"; J. Phys. Chem. 92:6661-6665; 1988.

MacKinnon, D.J., Dutrizac, J.E., Brannen, J.M. and Hardy, D.J., "The behaviour of thiourea and flotation reagents in zinc electrowinning circuits"; Metal. Trans. 19B:187-199; 1988.

MacKinnon, D.J., Brannen, J.M. and Morrison, R.M., "The effect of thiourea on zinc electrowinning from industrial acid sulphate electrolyte"; J. Appl. Electrochem. 18:252-256; 1988.

Pouskouleli, G., 'Metallorganic compounds as preceramic materials II. Oxide ceramics"; Ceramics International; 1988.

Riveros, P.A., "Ion exchange recovery of gallium from Bayor liquors"; Hydrometallurgy; 1988.

Riveros, P.A., "Studies on the solvent extraction of gold from cyanide media"; Hydrometallurgy; 1988.

Tan, K.G. and Bedard, P.L., "Development of a mini-plant chlorinator for ferric chloride leach processes"; Can. J. Chem. Eng. 66:8:632-636; 1988.

Presentations

Ahmad, A., Wheat, T.A., Kuriakose, A.K. and Quon, D.H.H., "The effect of processing parameters on the properties of modified lead titanate"; Can. Ceram. Soc. Annual Meeting, Toronto; February 1988.

Ahmed, S.M., Leduc, J. and Trudel, J., "Studies of the field dependent photoluminescence of n-GaAs electrodes with and without cobalt films"; J. Electrochem. Soc. 135:3015-3022; 1988.

Aota, J., Kuriakose, A.K., Wheat, T.A. and Quon, D.H.H., "The fabrication of zirconia-toughened mullite ceramics (ZTM)"; 86th Annual Convention of the Can. Ceram. Soc., Toronto; February 1988.

Barkley, D.J. and Eichron, P.A., "Dynamic ion-exchange chromatography for the determination of rare earths in samples from metallurgical processes"; 17th International Symposium on Chromatography, Vienna, Austria; September 1988.

Cabri, L.J., "Application of the proton microprobe to mineral exploration and mineral processing"; Invited presentation, 24th Western Inter-University Geological Conference, Winnipeg; January 1988.

Cabri, L.J., "Overview on application of platinum mineralogy to mineral exploration and processing"; In: Process Mineralogy VIII, AIME/TMS; January 1988 (in Press).

Cabri, L.J., "La minéralogie de l'or"; CANMET Seminar, Val-d'or (Québec); February 1988.

Cabri, L.J., "The role of mineralogy in gold metallurgy"; Symposium on Heap Leaching in a Canadian Environment; CMP/CIM; Paper No. 2; Timmins; May 1988.

Craigen, W.J.S., Krysa, B.D., Brown, H.H. and Barlin, B., "Evaluation of the Great Central Mines (GCM) hydrometallurgical copper process for application to Hudson Bay Mining and Smelting (HBMS) copper concentrates"; Paper presented at the CIM 18th Annual Hydrometallurgy Meeting; Edmonton, Alberta; May 1988.

Dalton, J.L., "(1) Overview of radioactive materials available from the Certified Reference Materials Project; (2) Radiochemical measurements of nickel sulphide concentrates"; 4th Workshop on Analytical Chemistry related to Canada's Nuclear Industry, Kimberly, Ontario; May 1988.

Deschênes, G., "Hydrogen reduction: A new method for recovering gold from thiourea solutions"; 55ième congrès de l'ACFAS, Ottawa; mai 1987.

Deschênes, G., "New developments in gold recovery and purification"; 19th Ann. Meet. Canadian Mineral Processors; January 1987.

Deschênes, G., "Investigation on the potential techniques to recover gold from thiourea solution"; 26th Annual Conference of Metallurgist, Winnipeg; August 1987.

Deschênes, G., "Progrès et orientation de la recherche et du développement de l'industrie aurifère"; 2ième colloque sur l'or; Rouyn-Noranda; November 1987.

Deschênes, G., "Techniques de récupération de l'or d'une solution"; CANMET Seminar, Val d'Or; February 1988.

Deschênes, G., "Development and applications of thiourea for processing gold deposits"; CANMET Seminar, Timmins; November 1988.

Dutrizac, J.E., "The hydrothermal conversion of jarosite-type compounds to hematite"; Joint CANMET/EEC Seminar on Complex Sulphide Ores, Luxembourg; November 1988.

Dutrizac, J.E., "The use of applied mineralogy in zinc processing"; Seminar, Queen's University, Kingston; June 1988.

Gould, W.D., McCready, R.G.L., Rajan, S. and Krouse, H.R., "Stable isotope composition of sulphate produced during the bacterial oxidation of various metal sulphides"; Can. Soc. of Microbiol. Ann. Mtg., Windsor, Ontario; June 1988.

Gould, W.D. and McCready, R.G.L., "Applications of biotechnology for the Gold Mining industry"; CANMET Seminar, Timmins, Ontario; November 1988.

Gould, W.D., McCready, R.G.L., Salley, J., Rajan, S., Chalykoff, C. and Beaudette, L., "Microbial treatment of industrial effluents"; 1988 Annual BIOMINET Meeting; 1988.

Graham, J., "Progress report on the activities of ISO/TC 183 - copper, lead and zinc ores and concentrates"; Canadian Mineral Analysts Conference, Noranda, Quebec; September 1988.

Haque, K.E., "Radium(226) removal from a contaminated soil"; US-EPA Workshop in Extractive Treatment of Excavated Soil, Edison, N.Y.; December 1988.

Haque, K.E., "The pretreatment options for refractory gold concentrate"; Presented at the CANMET Seminar at Timmins; November 1988.

Haque, K.E., "A review of CANMET's acid chloride leaching of uranium ores"; Presented at the Uranium and Electricity Symposium held in Saskatoon, Sask.; September 1988.

Haque, K.E. and Cienski, T., "Alkaline cyanide leaching of gold ores"; Presented at the CANMET Seminar held in Val d'Or, Quebec; February 1988.

Kuriakose, A.K., Wheat, T.A., Quon, D.H.H., Ahmad, A. and Aota, J., "The effect of precursor raw materials on the tetragonal zirconia content of alumina-zirconia ceramics"; Can. Ceram. Soc. Annual Meeting, Toronto; February 1988.

Langley, W.S., Carette, G.G. and Malhotra, V.M., "Structural concrete incorporating high-volumes of ASTM Class F fly ash"; TRB Annual Meeting, Washington, D.C.; January 1988.

MacDonald, R.J.C., Savard, S., "Federal mineral research and technology under the Canada/Provincial Mineral Development Agreements"; AIM Annual General Meeting, Edmonton, Alberta; May 1988.

Malhotra, V.M., "New materials for quality concrete"; Invited Presentation at the Fifth Building and Construction Congress, Montreal; November 1988.

Malhotra, V.M., "Needed methodology for testing concrete repair materials"; Invited Presentation at the ACI Quebec Chapter, Montreal; November 1988.

Malhotra, V.M., "Chloride for permeability of high-volume fly ash concrete"; Fall meeting of the American Concrete Institute, Houston; October 1988.

Malhotra, V.M., Carette, G.G. and Bremner, T.W., "Current status of CANMET studies on the durability of concrete containing supplementary cementing materials in marine environment"; 2nd CANMET/ACI International Conference on Performance of Concrete in Marine Environment, St. Andrews, N.B.; August 1988.

Malhotra, V.M., "Use of fly ash, slag and silica fume in North America and Europe"; Invited Presentation at the International Workshop on the Use of Fly Ash, Slag, Silica Fume and Other Siliceous Materials in Concrete, Sydney, Australia; July 1988.

Malhotra, V.M., "Silica fume, fly ash and slag: their role in making better concrete"; Invited 2nd Annual Lecture at the Meeting of the ACI Singapore Chapter, Singapore; July 1988.

McCready, R.G.L. and Salley, J., "Biotechnological treatment of mine effluents"; Nat'l. Conven. of the Water Res. Assoc., Saskatoon, Sask.; June 1988.

McNamara, V.M., "The AVR process for cyanide recovery, and cyanogen control for barren recycle and barren bleed"; Presented at Vancouver, February 1989 and Toronto, March 1989 at Seminars on Gold Mill Treatment of Effluent sponsored by Environment Canada and the B.C. and Ontario Mining Associations, respectively.

McNamara, V.M. and Ritcey, G.M., "Cyanide abatement processes for gold mill effluent treatment"; Presented at Timmins '88 and Val d'Or '88 CANMET Seminars on Gold Research and published in the respective proceedings; 1988.

Mikhail, S.A., Turcotte, A.M. and Bowman, W.S., "A study of the decomposition of higher cobalt aresenides by thermal analysis"; Presented at the 17th North American Thermal Analysis Society Conference; ed. C.M. Earnest; 46-52; 1988.

Nawwar, A.M. and Malhotra, V.M., "Development of a test method to determine the resistance of concrete to ice abrasion and/or impact"; 2nd CANMET/ACI International Conference on Performance of Concrete in Marine Environment, St. Andrews, N.B.; August 1988.

Petruk, W., "Recent progress in mineralogical investigations related to gold recovery"; Timmins, CANMET and Ontario Mining Association Meeting; November 24, 1988.

Quon, D.H.H., Wang, S.S.B., Aota, J., Wheat, T.A., Kuriakose, A.K. and Torrie, G., "Hydrothermal synthesis of zirconia and the preparation of zirconia-mullite composites"; 1989 Annual Convention of Can. Ceram. Soc.; February 1989.

Riveros, P.A., "Advance in ion exchange and solvent extraction for gold recovery"; Presented at Timmins '88 CANMET Seminar on Gold Research and Publication in the Proceedings; November 1988.

Ryan, D.H., Strom-Olsen, J.O., Provencher, R. and Townsend, M.G., "Transverse spin freezing in α-$Fe_{92}Zr_8$"; J. Appl. Phys. 64:5787-5791; 1988.

Steger, H.F., "Quality control is like knowledge - A little bit can be dangerous"; 4th Workshop on Analytical Chemistry related to Canada's Nuclear Industry, Kimberly, Ontario; May 1988.

Sutarno, R. and Bowman, W.S., "ISO/TC 183 - Precision of ISO draft methods for the determination of Au, Ag and Cu in copper concentrates"; Canadian Mineral Analysts Meeting, Noranda, Quebec; September 1988.

Tan, K.G. and Bedard, P.L., "Systems modelling in hydrometallurgy"; 38th Canadian Chemical Engineering Conference, Edmonton; October 1988.

Townsend, M.G., "Transverse spin freezing in α-$Fe_{92}Zr_8$"; Invited paper, International Meeting on Magnetism and Magnetic Materials, Vancouver, British Columbia; July 1988.

Townsend, M.G., "Statistics and radon measurement"; Seminar, Atomic Energy Control Board, Elliot Lake Office, Elliot Lake, Ontario; October 1988.

Wheat, T.A., "Advanced functional ceramics activity at federal government laboratories"; CUICAC Workshop, Toronto; May 1988.

Wilson, L.J., "Investigation of the oxidation of skutterudite by thermal analysis"; Paper presented at the 17th North American Thermal Analysis Society Conference; Orlando, Florida; October 1988.

Wilson, L.J., "Investigation of the oxidation of niccolite and skutterudite by thermal analysis"; Seminar presented at Noranda Technology Centre, Pointe Claire, Quebec; October 1988.

CANMET Reports (CM)

CM 87-7E 30.95.00
Moon, K.S. and Sirois, L.L., "Theory and application of column flotation"; November 1988.

Special Reports (SP)

SP 87-10 30.46.01
McCready, R.G.L., "BIOMINET proceedings".

SP 88-2 30.05.02
Gow, W.A. and Loucks, N.D., "Index of mineral processing projects".

SP 88-3 30.86.01
Filion, M., "Research plan - RATS".

National Uranium Tailings Program (NUTP)

NUTP-4E&F
Dalton, J.L. and Bowman, W.S., "Vegetative radionuclide reference materials/ Matériaux de référence d'origine végétale, contenant des radionucléides".

Division Reports

Investigation Reports (IR)

MSL 87-142 (IR) 30.21.02
Andrews, P.R.A., "Beneficiation of two drill core samples of kaolinised sand from Black Island, Manitoba"; December 1987.

MSL 87-143 (IR) 30.21.02
Andrews, P.R.A. and O'Shaughnessy, D.P., "Preliminary assessment of a Bird River deposit"; November 1987.

MSL 87-167 (IR) 30.21.02
Andrews, P.R.A. and Kelly, W., "A preliminary study of the beneficiation of a sample of sillimanite from Clarendon, South eastern Ontario"; December 1987.

MSL 88-14 (IR) 30.05.01
Wilson, J.M.D., Petruk, W. and Pinard, R., "Quantitative mineralogy of chromite ore from Bird River, Manitoba"; August 1988.

MSL 88-39 (IR) 30.13.02
Cameron, W.H. and Reynolds, V.G., "Investigation to produce an iron concentrate of low manganese content from Wabush rougher spiral tailings"; March 1988.

MSL 88-52 (IR) 30.29.01
Wheat, T.A., Ahmad, A. and Canaday, J.D., "Software for the impedance analysis of ceramic dielectrics"; May 1988.

MSL 88-61 (IR) 30.05.02
Healy, R.E. and Petruk, W., "The mineral characteristics that affect metal recoveries from the Cu, Zn, Pb and Ag ores from Manitoba. Part 1. An investigation of the ore mineralogy of the Trout Lake Deposit with a view of predicting mineral liberation and metal recovery during ore dressing"; May 1988.

MSL 88-68 (IR) 30.61.02
Riveros, P.A., "A comparative evaluation of long-chain quaternary amines as extractants of gold from cyanide leach solutions"; May 1988.

MSL 88-78 (IR) 30.61.02
Muir, D.M., "Prospects for the recovery of gold from cyanide liquors and pulps by solvent extraction and by ion exchange"; June 1988.

MSL 88-84 (IR) 14.39.01
Cristovici, M.A. and McCarthy, D.R., "Investigation to eliminate the negative effect of dust-suppressing surfactants on flotation (Kidd Creek Ore)"; April 1988.

MSL 88-86 (IR) 30.21.02
Andrews, P.R.A., "Preliminary assessment of two samples of clay from New Brunswick"; April 1988.

MSL 88-89 (IR) 30.21.02
Andrews, P.R.A., "Beneficiation of two samples of wollastonite from Marmora, Ontario"; September 1988.

MSL 88-100 (IR) 30.21.02
Andrews, P.R.A., "Separation of graphite, biotite and micaceous minerals from a Nova Scotia garnet schist"; August 1988.

MSL 88-107 (IR) 30.29.01
Kuriakose, A.K., Wheat, T.A., Quon, D.H.H., Ahmad, A. and Giles, B., "The toughening of alumina by zirconia"; August 1988.

MSL 88-118 (IR) 30.05.01
Stemerowicz, A.I. and Leigh, G.W., "Final report on the concentration of Tally Pond massive sulphide ores from Buchans area, Newfoundland"; August 1988.

MSL 88-119 (IR) 30.29.01
Ahmad, A., Wheat, T.A., Kuriakose, A.K. and Berry, R., "Microcomputer based software for lattice parameter calculations for tetragonal systems"; September 1988.

MSL 88-121 (IR) 30.05.02
Stemerowicz, A.I. and Leigh, G.W., "Production of lead and zinc from the Faro deposit of Curragh Resources Corporation, Yukon Territory"; September 1988.

MSL 88-148 (IR) 30.61.03
Cabri, L.J., Stemerowicz, A.E., Pouskouleli, G. and Craigen, W.J.S., "Platinum metals recovery"; November 1988.

MSL 88-151 (IR) 30.13.06
Stemerowicz, A.I. and Leigh, G.W., "Preliminary bench-scale metallurgical investigation - Kidd Creek "C" ore"; December 1988.

MSL 89-8 (IR) 30.13.01
Leung, J. and Laguitton, D., "An algorithm for data substitution in the on-line expert system"; January 1989.

Technical Reports, Technical Memos, Progress Reports, Information Reports (TR)

MSL 85-158 (TR) 50.62.03
Hamer, C.A. and Liang, D.T., "Sulphur and metals capture during combustion of syncrude coke in a circulating fluidized bed combustor"; December 1985.

MSL 87-140 (TR) 30.61.02
Gao, X. and Molnar, R.E., "Solvent extraction of gold from leach slurry"; October 1987.

MSL 88-5 (TR) 30.61.02
Chen, T.T. and Beaulne, J.M., "Mineralogy of gold in the rod mill discharge and in the final copper concentrate from Mines Northgate Inc., Chibougamau, Quebec"; January 1988.

MSL 88-74 (TR) 30.21.02
Collings, R.K., "Preparation and evaluation of Nova Scotian industrial minerals as fillers and extenders"; April 1988.

MSL 88-81 (TR) 50.62.03
Hamer, C.A. and Owens, D.R., "Scanning electron microscopic examination of Chatham circulating fluidized bed combustor ashes"; June 1988.

MSL 88-138 (TR) 30.69.02
Sutarno, R., "ISO/TC 102/SC 2 - 14th International meeting Belo Horizonte, Brazil, 1988-10-23/28"; November 1988.

MSL 89-30 (TR) 13.03.01
Bilodeau, M., Ter Heijden, E. and Laguitton, D., "CRSHEX - A computer program for crushing circuit simulation - User's guide"; October 1988.

MSL 89-31 (TR) 30.13.01
Bilodeau, M. and Laguitton, D., "SIMBAL - A computer program for mineral processing circuit simulation - User's guide"; October 1988.

Literature Surveys (LS)

MSL 88-112 (LS) 30.13.02
Stefanski, M.J., "Circuitry instrumentation and process control - Literature Review; November 1988.

Patents and Applications

Brassinga, R.D., Fulford, G.D., McCready, R.G.L., Gould, W.D. and Beaudette, L., "The biodegradation of oxalate ions in aqueous solutions"; Filed August 14, 1988.

Demopoulos, G.P. and Ritcey, G.M., Pressure leaching of uranium ores in a chloride medium"; Canada Patent Application No. 1,247,372; December 28, 1988.

Deschênes, G., "Recovery of gold from leach solution"; Canada Patent Application No. 537,316; 1987.

Kuriakose, A.K., Wheat, T.A., Ahmad, A., Canaday, J.D. and Hanson, A.J., "Bonded hydrogen conducting solid electrolytes"; United States Patent Application 4,724,191; 1988.

Lakshmanan, V.I. and McCready, R.G.L., "Bioadsorption composition, process for the production thereof and process for the use thereof"; Draft Patent Application Prepared January 16, 1989.

McCready, R.G.L., Gould, W.D. and Salley, J., "Biorecovery of selenium"; Filed October 18, 1988.

McCready, R.G.L., Gould, W.D., Chalykoff, C., Salley, J. and Worgan, J., "Biodegradation of urea and ethylene glycol using a rotating biological contactor and a selected organism"; Patent Application in Preparation.

Riveros, P.A., "A combined ion exchange process for the recovery of gold"; Canada Patent Application 593,650-1; 1989.

Unedited Miscellaneous Reports

Canaday, J.D., Kuriakose, A.K., Wheat, T.A., Ahmad, A., Gulens, J. and Hildebrandt, B.W., "Bonded solid proton conductor/platinum electrochemical cells"; Meeting on Solid State Protonic Conductors IV, Exeter, U.K.; 1988.

Canaday, J.D., Kuriakose, A.K., Wheat, T.A. and Ahmad, A., "Measurements of the platinum/hydronium-Nasicon system"; Can. Ceram. Quart. 61:1:20; 1988.

Dutrizac, J.E. and Sunstrum, J.B., "Early Canadian lead smelters"; CIM Bull. 81:920:75-77; 1988.

Dutrizac, J.E., "The CANMET ferric chloride leach process - An overview"; Joint CANMET/EEC Seminar on Complex Sulphide Ores, Luxembourg; November 1988.

Ghosh, D., Jacobs, J., Das Gupta, S., Wheat, T.A., Kuriakose, A.K. and Murthy, M.K., "Developments in zirconia-toughened alumina"; Can. Ceram. Soc. Annual Meeting, Toronto; 1988.

Gould, W.D., "Biotechnology in the Mining industry"; State University of New York, Syracuse; April 1988.

Gulens, J., Longhurst, T.H., Kuriakose, A.K. and Canaday, J.D., "Hydrogen electrolysis at 300K using a Nasicon solid proton conductor"; Solid State Ionics 28-30:622-626; 1988.

Gulens, J., Hildebrandt, B.W., Canaday, J.D., Kuriakose, A.K., Wheat, T.A. and Ahmad, A., "Influence of water on the electrochemical response of a bonded nasicon protonic conductor"; Solid State Protonic Conductors IV, Exeter, U.K.; 1988.

Howell, W.H., Golding, J.A. and Ritcey, G.M., "Bench-scale mixer-settler study of the extraction and stripping of uranium from solutions"; Hydrometallurgy 19:11-13; November 1988.

Kuriakose, A.K., Canaday, J.D. and Wheat, T.A., "CANMET develops a proton conducting ceramic"; CFFTP Newsletter; February 1988.

Lakshmanan, V.I., Heinrich, G. and McCready, R.G.L., "Stabilization of biomass for the removal of uranium from diluted solutions by biosorption"; in Biotechnology in Minerals and Metals Processing 23:187-192; AIME; Las Vegas; 1989.

Malhotra, V.M., gave a series of invited lectures on Concrete Technology at the Structural Engineering Research Centre, Madras, India; August 1988.

Malhotra, V.M., gave a series of invited lectures on the National Council for Cement and Building Materials, New Delhi, India; August 1988.

Malhotra, V.M., "CANMET researches in concrete technology"; Invited Presentation at the Annual Meeting of the ACI Atlantic Chapter, Moncton, N.B.; February 1988.

Malhotra, V.M., "Freezing and thawing resistance of superplasticized concrete"; TRB Annual Meeting, Washington, D.C.; January 1988.

McCready, R.G.L., "Microbial desulphurization of coal"; BIOMINET Ann. Mtg., Calgary, Alberta; November 1988.

McMahon, G., Wang, S.S.B., Quon, D.H.H., Sood, R., Holt, R.T. and Maccagno, T.M., "A study on Whisker lithium aluminosilicate composites"; 27th Conf. Met. Soc. CIM, Montreal; August 28-31, 1988.

Petruk, W. and Mainwaring, P., "Image analysis short course"; CANMET; January 18, 1988.

Petruk, W., "Ore characteristics that affect mineral beneficiation during grinding"; Canadian Mineral Processors, Ottawa; January 1988.

Petruk, W., "Method of studying materials by image analysis and applications to Earth Sciences"; 24th Western Inter-University Geological Conference, Winnipeg; January 21, 1988.

Petruk, W., "Textural classification using an image analyzer"; Annual Meeting, METSOC CIM; August 29, 1988.

Petruk, W., "Applied mineralogy to evaluate mineral and metal recoveries from ores of Atlantic Provinces"; Fredericton, CIM, District 1, Annual Meeting; September 21, 1988 (CIM Distinguished Lecturer).

Petruk, W., "Evaluation of behaviour of iron ore minerals in concentrator of Iron Ore Company of Canada"; Montreal Branch of Canadian Mineral Processors, Montreal; October 26, 1988 (CIM Distinguished Lecturer).

Petruk, W., "Evaluating processes for optimum recoveries"; Noranda, West Quebec CIM Branch; November 4, 1988 (CIM Distinguished Lecturer).

Petruk, W., "Evaluating processes for optimum recoveries"; Kingston, Kingston CIM Branch; November 18, 1988 (CIM Distinguished Lecturer).

Petruk, W., "Ore characteristics that affect mineral beneficiation during grinding"; Luxembourg, Annual Meeting of EEC and CANMET; November 29, 1988.

Pouskouleli, G. and Wheat, T.A., "Recent trends in ceramics R&D, A global view".

Pouskouleli, G. and Wheat, T.A., "The International scene in advanced ceramics".

Ritcey, G.M. and Wong, E.W., "Methodology for crud characterization"; Presented at International Solvent Extraction Conference, ISEC '88, Moscow, USSR and published in the proceedings, Vol. II, pp. 116-119).

Ritcey, G.M., Molnar, R.E., Riveros, P.A., Wong, E.W., He, P.J., Gao, X. and Koegler, C., "Solvent extraction of gold from cyanide leach slurries"; Presented at International Solvent Extraction Conference, ISEC '88, Moscow, USSR, July 1988 and published in the proceedings, Vol. IV addendum).

Ritcey, G.M., "Tailings and environment, aspects of hydrometallurgy recovery"; Presented at First International Conference on Hydrometallurgy (ICHM), Beijing, China, October 1988 and published in the proceedings, pp. 11-22.

Ritcey, G.M., "Tailings management"; Lecture presented at "Possible Technologies for Gold and Precious Metals" Workshop, Laval University; May 1988.

Ritcey, G.M., "Cyanide destruction"; Lecture presented at "Possible Technologies for Gold and Precious Metals" Workshop, Laval University; May 1988.

Ritcey, G.M., "Tailings management"; Short Course presented at University of New South Wales, Australia; January 1988.

Ritcey, G.M., "Tailings management"; Short Course presented at BHP Ltd., Sydney, Australia; September 1988.

Ritcey, G.M., "Principles of solvent extraction"; Short Course presented at Shell Chemicals Ltd., Melbourne, Australia; September 1988.

Ritcey, G.M., "Tailings management and cyanide destruction/recovery"; Presented at Val d'or '88 CANMET seminar on Gold Research and Published in the Proceedings.

Tan, K.G., "Thiosalts '88"; Thiosalt Workshop/Seminar, Moncton; May 1988.

Wang, S.S.B., Quon, D.H.H., Torrie, G. and Wheat, T.A., "Hydrothermal synthesis of superfine zirconia powder"; Clay and Ceramics 61:1:19; 1988.

Wasserlauf, M., Condy, A.A., Wheeland, K. and Dutrizac, J.E., "Techno-economic evaluation of thiosalt treatment processes"; CIM Bull. 81:909:82-86; 1988.

PART E. PROFESSIONAL, TECHNICAL AND ADMINISTRATIVE STAFF

NAME	DEGREES	OCCUPATIONAL CATEGORY
Sirois, L.L.	B.A., B.Eng., (McGill); P.Eng.	Director MSL
Craigen, W.J.S.	B.Sc. (Queen's)	Phys. Sci.
ADMINISTRATION		
Bisson, S.		Admin. Support
Carbonetti, S.		Admin. Support
Cook, D.		Admin. Support
Desrochers, L.R.		Admin. Support
Emmerson, M.		Admin. Support
Groulx, P.		Admin. Support
Joly, A.		Admin. Support
Lamb, K.A.		Admin. Support
Lavallée, L.R.		Admin. Support
Lavergne, D.		Admin. Support
Lord, S.		Admin. Support
MacLeod, J.D.		Scientific Illustration
Mathurin, D.		Admin. Support
Moir, B.		Admin. Support
Palmer, M.		Admin. Support
Rochon, J.P.		Admin. Officer
Villeneuve, J.		Admin. Support

NAME	DEGREES	OCCUPATIONAL CATEGORY
CHEMICAL LABORATORY		
Steger, H.F.	B.Sc., Ph.D. (McMaster)	Manager
Guest, R.J.	B.Sc. (Acadia)	Asst. Manager Operations
Atkinson, J.E.	B.A. (Queen's)	Chemist
Barkley, D.J.	B.Sc. (Carleton)	Chemist
Carson, D.W.		Technologist
Charbonneau, R.		Technologist
Chenier, M.		Technologist
Churchill, T.R.	B.Sc. (Western Ontario)	Chemist
Cloutier, J.C.		Technologist
Cyfracki, E.		Technologist
Dalton, J.L.	B.Sc. (Manitoba); M.Eng. (Carleton); C. Chem.	Chemist
Desjardins, L.		Technologist
Donaldson, E.M.	B.Sc. (Manitoba)	Res. Sci.
Fortin, R.A.		Technologist
Graham, J.A.	B.Sc. (Carleton)	Chemist
Guibord, M.P.		Admin. Support
Guillas, R.J.		Technologist
Hole, J.C.	B.A. (Toronto)	Chemist
Horton, R.E.	B.Sc. (Carleton)	Chemist
Hunt, G.A.	B.Sc. (Carleton)	Chemist
Lalande, L.L.		Lab. Support
Lalonde, C.R.		Technologist
Lalonde, R.C.	B.Sc. (Carleton)	Chemist

NAME	DEGREES	OCCUPATIONAL CATEGORY
Leaver, M.E.	B.Sc. (Queen's)	Chemist
MacEachern, E.H.	B.Sc. (Mount Allison)	Chemist
McIntosh, D.G.		Tech. Support
McCorkell, R.H.	M.Sc., Ph.D. (Manitoba)	Chemist
McCulloch, L.		Technologist
Moloughney, P.		Technologist
Nelson, G.L.		Technologist
Palombo, D.P.		Technologist
Provencher, R.	B.Sc., M.Sc., Ph.D. (Sherbrooke)	Res. Sci.
Pugliese, R.J.		Technologist
Richardson, G.		Technologist
Richer, P.		Technologist
Sawchyn, M.N.		Technologist
Sheldrick, D.		Technologist
Smith, C.W.	M.Sc., Ph.D. (Queen's)	Res. Sci.
Townsend, M.G.	B.Sc., Ph.D. (Southhampton)	Res. Sci.
Tremblay, R.J.J.		Technologist
Varette, D.M.		Admin. Support
Westra, P.		Tech. Support
Wittwer, J.W.	B.Sc. (Carleton)	Chemist

NAME	DEGREES	OCCUPATIONAL CATEGORY
EXTRACTIVE METALLURGY LABORATORY		
Campbell, M.C.	B.Sc. (St. Francis Xavier) B.Eng. (N.S.T.C.), D.I.C., M.Sc. (London); P.Eng.	Manager
Ahmed, S.M.	B.Sc., M.Sc. Ph.D. (Saskatchewan)	Res. Sci.
Béchard, G.	B.Sc., M.Sc. (Univ. du Québec)	Phys. Sci.
Bedard, P.L.		Technologist
Bell, D.H.	B.A.Sc. (Toronto); Ph.D. (London); D.I.C. (Imperial College)	Phys. Sci.
Bowman, W.S.	B.Sc. (Carleton)	Technologist
Brannen, J.M.		Technologist
Carter, L.E.		Technologist
Chalykoff, C.	B.Sc. (Carleton)	Technologist
Davidson, G.R.	B.Sc. (Carleton)	Technologist
Deschênes, G.	B.Sc., M.Sc. (Laval)	Phys. Sci.
Dinardo, O.	B.Sc. (Carleton)	Phys. Sci.
Dutrizac, J.E.	M.A.Sc., Ph.D. (Toronto)	Res. Sci.
Gould, W.D.	B.Sc. (Manitoba); M.Sc. Ph.D. (Alberta)	Res. Sci.
Griffith, W.F.		Technologist
Hamer, C.	B.E. (N.S.T.C.), M.Sc. (Queen's); P.Eng.	Res. Sci.
Haque, K.E.	M.Sc., Ph.D. (Ottawa)	Res. Sci.
Hardy, D.J.		Technologist
Joly, M.		Tech. Support
Karwowska, R.	M.Sc., Ph.D. (Warsaw)	Technologist

NAME	DEGREES	OCCUPATIONAL CATEGORY
Kearns, J.B.		Technologist
Kondos, P.	B.A. (National Technical University, Athens), M.A.Sc., Ph.D. (McGill University)	Res. Sci.
Laforest, D.		Technologist
Liang, D.	B.Sc., M.Sc. (Queen's)	Engineer
MacKinnon, D.J.	B.Sc., M.A.; Ph.D. (Ottawa)	Res. Sci.
McCready, R.G.L.	B.Sc., M.Sc. (Alberta); Ph.D. (Calgary)	Res. Sci.
McNamara, V.M.	B.Sc., B.Eng., M.A.Sc. (Toronto); P.Eng.	Res. Sci.
Mikhail, S.A.	B.Sc., Ph.D. (Cairo); Dr.Eng. (Norway)	Res. Sci.
Molnar, R.	B.Eng. (McGill); Ph.D. (Univ. of London); D.I.C.	Res. Sci.
Morrison, R.M.	B.Sc., Ph.D. (UBC)	Res. Sci.
Paquette, L.A.		Admin. Support
Pouskouleli, G.	B.Sc. (Aristotelian Univ., Greece); M.Sc. (Université de Montréal); Ph.D. (McGill Univ.)	Res. Sci.
Prud'homme, P.J.A.		Technologist
Rajan, S.		Technologist
Ritcey, G.M.	B.Sc. (Dalhousie)	Res. Sci.
Riveros, P.	Ph.D. (Queen's Univ.) M.Sc. (Univ. of Bradford, U.K.)	Res. Sci.
Rolko, V.H.E.	B.Sc. (Manitoba)	Chemist
Salley, J.	B.Sc. (Ottawa)	Phys. Sci.
Sanmugasunderam, V.	B.Sc. (Univ. of Ceylon); M.Sc. (Univ. of Wales); Ph.D. (UBC)	Res. Sci.

NAME	DEGREES	OCCUPATIONAL CATEGORY
Shimano, D.Y.	B.Sc. (Concordia)	Phys. Sci.
Skeaff, J.M.	B.Sc., M.Sc., Ph.D. (Toronto)	Res. Sci.
Sunstrum, J.		Admin. Support
Sutarno, R.	B.E., M.E., Ph.D. (N.S.T.C.); P.Eng.	Res. Sci.
Tan, K.G.	M.Sc.Chem. (Univ. of Aachem, Germany); Ph.D. (Carleton)	Res. Sci.
Taylor, J.B.		Technologist
Tremblay, G.	B.Eng. (Civil) (Carleton)	Phys. Sci.
Turcotte, A.M.		Technologist
Wallingford, G.		Technologist
Weatherell, C.	B.Sc. (Waterloo)	Chemist
Webster, A.H.	B.A., M.A., Ph.D. (UBC)	Res. Sci.
Wilson, L.J.	B.Sc. (McMaster)	Phys. Sci.
Wong, E.W.		Technologist

MINERAL PROCESSING LABORATORY

Campbell, F.R.	Eng. D. (St. Francis Xavier); B.Eng. (N.S.T.C.); Ph.D. (London); D.I.C. (Imperial College)	Manager
Aota, J.	M.Sc. (UBC)	Phys. Sci.
Ahmad, A.	B.Sc., M.Sc., Ph.D. (New Brunswick)	Res. Sci.
Andrews, P.R.A.	B.Sc. (London); M.Eng.Sc. (Melbourne)	Res. Sci.
Beaulne, J.M.		Technologist
Besso, K.M.	B.Sc. (Montreal)	Phys. Sci.
Bilodeau, A.	B.Sc. (Laval)	Engineer

NAME	DEGREES	OCCUPATIONAL CATEGORY
Bilodeau, M.	B.Sc. (Laval)	Phys. Sci.
Boisclair, M.		Technologist
Brearley, G.D.		Technologist
Cabri, L.J.	B.Sc., M.Sc., Ph.D. (McGill)	Res. Sci.
Cameron, W.H.	B.Sc. (Queen's)	Phys. Sci.
Campbell, R.B.		Technologist
Canaday, J.D.	M.BA (Univ. of Arizona); B.Sc. (Univ. of Oklahoma); M.Sc. (Univ. of Calgary); M.Sc., Ph.D. (Univ. of Guelph)	Res. Sci.
Carette, G.G.	B.Sc. (Laval)	Eng.
Carrière, P.		Technologist
Chen, T.T.	B.Sc., M.Sc., Ph.D. (Cornell)	Res. Sci.
Chevrier, R.		Technologist
Chow, M.		Admin. Support
Cienski, T.	B.A. (Poland)	Phys. Sci.
Cimon, D.	B.Sc., M.Sc. (Laval)	Phys. Sci.
Collings, R.K.	B.Eng. (N.S.T.C.); P.Eng.	Res. Sci.
Cristovici, M.	B. Mining and Metallurgical Eng. (Bucharest); P.Eng.	Res. Sci.
Douglas, E.	B.Sc. (Chem. Eng.) (Argentina); Ph.D. (McGill)	Res. Sci.
Doyle, D.M.	B.Sc. Min. Eng. (Michigan Technical Univ.)	Phys. Sci.
Feasby, D.G.	B.Sc., M.Sc. (Queen's)	Phys. Sci.
Hanson, A.J.		Technologist

NAME	DEGREES	OCCUPATIONAL CATEGORY
Jambor, J.L.	B.A., M.Sc., Ph.D. (Carleton)	Res. Sci.
Joly, T.		Admin. Support
Kelly, W.M.		Technologist
Kuriakose, A.K.	B.Sc., M.A., Ph.D. (Madras, India)	Res. Sci.
Lacelle, L.		Tech. Support
Laflamme, J.H.		Technologist
Laguitton, D.	Chem. Eng. (Rennes); D.Sc. (Laval)	Res. Sci.
Lamothe, J.M.	B. Mining Eng. (Ecole Polytechnique Montreal)	Engineer
Lavallée, M.	B.Eng. Mining (McGill)	Phys. Sci.
Leigh, G.		Technologist
Lemieux, G.		Technologist
Leung, J.H.C.	B.Sc. (Taiwan); M.Sc. (Waterloo)	Phys. Sci.
Loucks, N.D.		Admin. Support
Mainwaring, P.R.	B.Sc. (UWO); Ph.D. (Toronto)	Res. Sci.
Malhotra, V.M.	B.Sc., B.E. (W. Australia)	Res. Sci.
Mathieu, G.I.	B.A., B.Sc. (Laval)	Res. Sci.
McDonald, A.G.		Technologist
Mirkovich, V.V.	Ph.D. (Toronto)	Res. Sci.
Moon, K.S.	B.Sc. (Seoul National Univ.); M.A.Sc. (UBC); Ph.D. (Berkeley)	Res. Sci.
Morin, L.		Technologist
Owens, D.R.		Technologist

NAME	DEGREES	OCCUPATIONAL CATEGORY
Painter, K.E.	B.Sc. (Carleton)	Technologist
Petruk, W.	B.Eng., M.Sc., Ph.D. (McGill)	Res. Sci.
Pinard, R.G.		Technologist
Prud'homme, P.J.H.		Technologist
Quon, D.H.H.	B.Sc. (National Sun Yat Sen U); M.Sc. (Ohio State); Ph.D. (Michigan)	Res. Sci.
Raicevic, M.		Technologist
Reynolds, V.G.	B.Sc. (Carleton)	Phys. Sci.
Rouleau, J.P.		Tech. Support
Scharf, R.I.		Technologist
Sivasunderam, V.	B.Sc. (Srilanka); M.Sc. (Massachusetts)	Phys. Sci.
Soles, J.A.	B.A.Sc., M.A.Sc. (British Columbia); Ph.D. (McGill); P.Eng.	Res. Sci.
Stefanski, M.	B.Sc., M.Sc., Ph.D. (Katowce); Ph.D. (Krakow)	Phys. Sci.
Stemerowicz, A.I.	B.Sc. (Queen's); P.Eng.	Res. Sci.
Szymanski, J.T.	B.Sc., Ph.D. (London)	Res. Sci.
Venturino, M.		Admin. Support
Wang, S.S.B.	B.Sc. (Hong Kong Baptist); M.Sc. (California); Ph.D. (Toronto)	Phys. Sci.
Wilson, J.M.D.	B.Sc., M.A.Sc. (Queen's)	Phys. Sci.